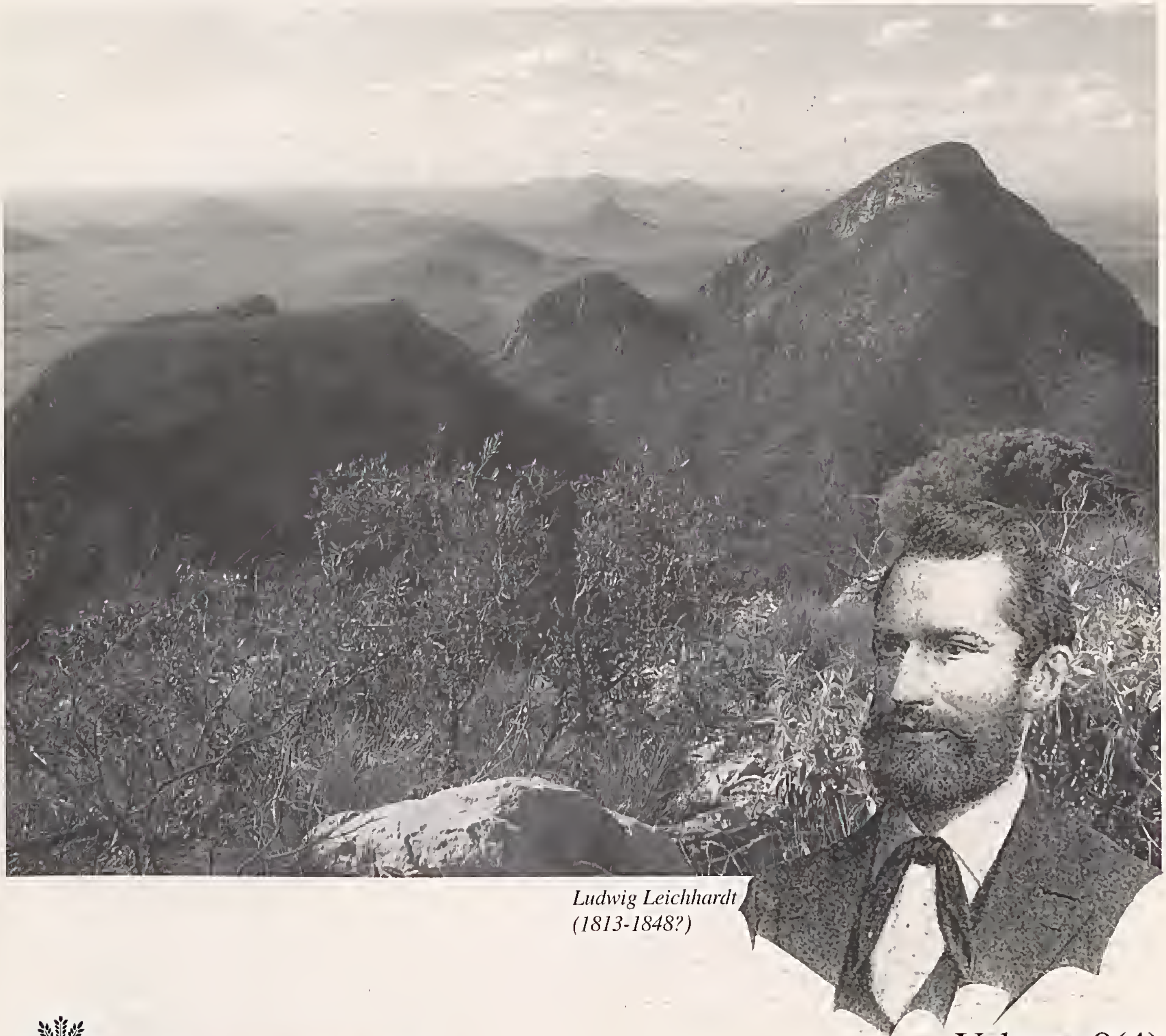
Cunninghamia

A journal of plant ecology for eastern Australia



Ludwig Leichhardt
(1813-1848?)

Botanic Gardens Trust
SYDNEY

Volume 9(4)
2006

Cunninghamia

A journal of plant ecology for eastern Australia

Cunninghamia: **a journal of plant ecology for eastern Australia** publishes original research papers on all aspects of plant ecology with particular emphasis on the vegetation and flora of eastern Australia. Descriptive, experimental and historical studies of plant communities, populations, individuals, their interactions with other organisms and their management are acceptable. Acceptance is the responsibility of an editorial committee chaired by the Scientific Editor. All papers are peer-reviewed.

Cunninghamia is published twice a year by the Botanic Gardens Trust.

Annual Subscription rates for 2006 (2 issues)

	Within Australia	*Overseas*
Individuals	$77	A$105 (surface mail)
Institutions	$110	A$165 (surface mail)

For subscriptions please send a cheque made out to the ***Botanic Gardens Trust*** addressed to:

The Administrative Officer,
Mount Annan Botanic Garden,
Mount Annan Drive, Mount Annan 2567

Subscription enquiries phone (02) 4648 2477

Issues of ***Cunninghamia*** (including back issues) are available from the Gardens Shops at the Royal Botanic Gardens, Mount Annan Botanic Garden and Mount Tomah Botanic Garden. For phone enquiries contact the Gardens shop at Mount Annan Botanic Garden (02) 4634 7935.

Order forms for subscriptions and back issues can be printed from our website: www.rbgsyd.nsw.gov.au.

Allan Cunningham, botanist and explorer (1791–1839)

Cover: The spectacular volcanic plugs of the Peak Ranges to the east of Clermont, Queensland, photographed from Ropers Peak. Many of the tors were named by Leichhardt, who rode a circuit around those in the foreground in a fruitless search for water in January- February 1845. Photo: Don Butler

Inset: Image of Ludwig Leichhardt (1813-1848?)
Lithograph of Ludwig Leichhardt reproduced from Dr Ludwig Leichhardt's Briefe an seine Angehorigen.
Herausgegeben im Auftrage der Geographischen Gesellschaft in Hamburg von Dr. G. Neumayer und Otto Leichhardt

Cunninghamia

A journal of plant ecology for eastern Australia

Volume 9(4): 451–595 • 2006

This disastrous event staggered me: Reconstructing the botany of Ludwig Leichhardt on the expedition from Moreton Bay to Port Essington, 1844-45
R. J. Fensham, A.R. Bean, J. L. Dowe and C. R. Dunlop 451

Leaf, tree and soil properties in a *Eucalyptus saligna* forest exhibiting canopy decline
Christine Stone and Jack A. Simpson 507

Quantifying the abundance of four large epiphytic fern species in remnant complex notophyll vine forest on the Atherton Tableland, north Queensland, Australia
Jason Cummings, Michelle Martin and Anne Rogers 521

The effect of population structure, plant size, herbivory and reproductive potential on effective population size in the temperate epiphytic orchid, *Sarcochilus australis*
Raymond Tremblay 529

The natural distribution and ecology of *Blandfordia cunninghamii* (Blandfordiaceae)
David Coleby 537

African Olive (*Olea europaea* subsp. *cuspidata*) as an environmental weed in eastern Australia: a review
Peter Cuneo and Michelle R. Leishman 545

Distribution and diversity of exotic plant species in montane to alpine areas of Kosciuszko National Park
Roxana Bear, Wendy Hill, Catherine M.Pickering 559

Primary vegetation development on the sand spit of Shallow Inlet, Wilsons Promontory, southern Victoria
Petrus C. Heyligers 571

***Cunninghamia* 9(4): 451–595 • November 2006**

Scientific Editor
Doug Benson
Royal Botanic Gardens,
Mrs Macquaries Road, Sydney, Australia 2000.
Email: doug.benson@rbgsyd.nsw.gov.au

Scientific Editorial Committee
Brett Summerell, John Benson, Bob Makinson,
Tony Auld.

Typesetting and Production
Julia Sideris

Printer
Ligare Pty Ltd

ISSN 0727-9620
© 2006 Botanic Gardens Trust
Royal Botanic Gardens, Mrs Macquaries Rd,
Sydney, Australia 2000.

www. rbgsyd.nsw.gov.au

This disastrous event staggered me: Reconstructing the botany of Ludwig Leichhardt on the expedition from Moreton Bay to Port Essington, 1844-45

R. J. Fensham, A.R. Bean, J. L. Dowe and C. R. Dunlop

R. J. Fensham[1], A.R. Bean[1], J. L. Dowe[2] and C. R. Dunlop[3] ([1]Queensland Herbarium, Environmental Protection Agency, Mt Coot-tha Rd, Toowong, Queensland, Australia 4068; [2]Australian Centre for Tropical Freshwater Research, James Cook University, Townsville, Qld 4811, Australia; [3]Springbrook, Queensland; *rod.fensham@epa.qld.gov.au)*

Abstract: Ludwig Leichhardt had to abandon a large and important collection of botanical specimens during his Expedition from Moreton Bay to Port Essington. Here we attempt to assess the significance of the lost collection by identifying the botanical references in his detailed published journal from the journey. From Leichhardt's description of the plants and their habitats, and with our accurate knowledge of current distribution, it has been possible, in most cases, to identity his botanical references to a single species. In other cases there is lower degree of certainty. Well over one hundred of the species recorded in Leichhardt's journal would have been new to science at the time if specimens had survived. The record does identify some potential locations for species that would represent range extensions and suggests an indigenous status for a number of plant species that where previously considered exotic. Certainly Leichhardt was a talented botanist and his significant contribution to Australian natural science should be recognised.

***Cunninghamia* (2006) 9(4): 451–506**

Introduction

Ludwig Leichhardt, the German-born explorer of Australia in the 1840s has evoked a mixed reaction from historians and biographers. In the most recent and scholarly biography *The dauntless explorer,* Colin Roderick (Roderick 1988) has largely restored his character from previous aspersions and highly commended his exploratory achievements. Roderick's version of the record contrasts sharply with that of the accomplished ornithologist Alec Chisholm (Chisholm 1955) who championed the contribution of John Gilbert, Leichhardt's travelling companion and fellow naturalist. Gilbert is portrayed as a highly capable man of faultless integrity in contrast to the incompetent, deceitful and egotistical Leichhardt. In the preface to *Strange new world*, Chisholm's character assassination extends to Leichhardt's contribution as a naturalist: *One variant* [from the previous edition] *is a modifying of my tribute to Leichhardt's botanical work. His results, I am told by a leading botanist were "infinitesmal* (sic) *compared with those of Mitchell and certain other explorers" and the wonder is that so many plants were given his name.* Leichhardt may not have fulfilled his potential but commentators now regard Leichhardt as an extremely capable botanist who made a substantial and underrated contribution to the development of botanical knowledge in Australia (e.g. Barker and Barker 1990; Dowe 2005). In this paper we provide a more detailed examination of Leichhardt's contribution as a botanist during his most significant exploratory achievement, the Expedition from Moreton Bay to Port Essington.

Leichhardt's botanical background

The Leichhardt family was of poor rural stock and did not have the money to provide education for their children. However, the intellectually gifted Ludwig was able to obtain a formal training through the generous patronage of the family of his English friend William Nicholson. He took full advantage of the opportunity and was obviously a diligent student at various institutions in Göttingen, Berlin, London and Paris between 1832 and 1841. The education gave Leichhardt grounding in anthropology, philosophy, comparative religion, languages and medicine, but his focus was on the natural sciences, including zoology, geology and botany. Probably the most important component of his formal botanical training was undertaken at the Jardin des Plantes in Paris under the tutelage of the distinguished botanical scholar Adrien Jussieu. Adolphe Brongniart, of the same institution, trained him in palaeobotany and Leichhardt later collected fossils and wood samples for him while in Australia.

Leichhardt arrived in Sydney in February 1842 and spent his first two and a half years travelling the recently settled areas between Sydney and the Moreton Bay district (now south-east Queensland), avidly devoted to the study of natural history. His interests were broad, encompassing geology, meteorology, palaeontology, anthropology, zoology and botany, and his journals and letters are a rich source of observations and thoughtful insights into the natural world.

Leichhardt had access to the limited botanical texts of relevance to Australia including the first seven volumes of

De Candolle's (1823–1873) *Prodromus systematis naturalis regni vegetabilis*, Robert Brown's (1810) *Prodromus florae Novae Hollandiae et insulae Van Diemen* and Endlicher's (1836–1841) *Genera Plantarum* (Aurousseau 1968, p. 697, 876, 878, 905). In the company of his newly found friend and patron, Lieutenant Robert Lynd, Leichhardt engaged in extensive field-work and plant collecting and soon developed a thorough working knowledge of the Australian flora. For a while, he planned to produce (with Lynd) a Flora of Sydney (Aurousseau 1968, p. 493, 513, 591). Leichhardt was obsessive and energetic, and his prodigious output of physical collections (botanical specimens, seeds, timbers, rocks, bones, fossils etc.) and his written observations on a wide range of topics, was only sustained by working '*…from 7 in the morning until midnight*' (Aurousseau 1968, p. 778).

The Port Essington Expedition

Leichhardt's first major expedition from Moreton Bay to Port Essington in 1844–1845 (Fig. 1), is regarded as one of the great Australian exploratory journeys and was diligently chronicled by Leichhardt in a widely read published journal (Leichhardt 1847a). The permanent members of the expedition were Leichhardt, John Gilbert an ornithologist sponsored by John Gould, John Roper, James Calvert, emancipated convict William Philips, an 18-year-old John Murphy and two Aboriginals, Harry Brown and Charley Fisher. The party employed packhorses and bullocks to carry supplies and provide fresh meat. The journey took 14 and a half months, far more than the five to six months predicted by Leichhardt before the journey started. The mode of travel was almost always dictated by concerted efforts to locate a campsite where water was close at hand (McLaren 1996). To avoid haphazard travel for all the men and animals, a suitable campsite for the next night was located (usually by Leichhardt and one of the Aboriginals) before the party at large proceeded. Hence campsites were often spaced within half a days travel. While scarcity of water was the main factor that slowed their progress, there is no doubt that the journey was also prolonged by Leichhardt's obsessive thirst for natural history. The party regularly stayed more than one day at a campsite, and at times there seemed no compelling reason other than to allow Leichhardt adequate time for botanical studies.

Leichhardt exhibited great leadership and fortitude on the expedition (Roderick 1988, McLaren 1996). He described his onerous personal duties in a letter to his friend and botanical agent Gaetano Durando:

I was not the easy traveller, who has everything at hand, and can pay all his attention to botany. I was everything, leader of the party, bullock driver, having to load, and unload 3 bullocks sometimes several times during the day. All the cares of such a position were upon me, all the anxieties during difficulties and dangers. The arrangement of our camps, the serving out of our provisions, the killing of our bullocks, the mending of the harness, the carrying on of my log, the daibook of my route, determining the latitude and longitude, and the nightly watches.—You will easily imagine, that even allowing I did my best, a man given entirely to one occupation could have done much more. (Aurousseau 1968, p. 869).

In a later letter, Leichhardt provided more detail of his botanical method:

On my Expeditions almost every one assists in collecting plants and objects of natural history; but those who are not versed in botany will only take the most showy objects; I myself look out for the less conspicuous but perhaps equally interesting. Every 3–4 weeks I unite the dried specimens into families and the latter into sections, which enables me to compare and throw away those specimens, of which I have accumulated beyond the fixed number. I cannot go on ad infinitum in collecting, for my means of carriage are very limited.--Nor can I pay attention in drying, for every one of us has plenty to do besides. (Aurousseau 1968, p. 969).

His efforts appeared to yield substantial dividend as his botanical collection expanded.

The length of time 14 ½ months enabled me to render the collection very perfect, as I remained long enough within the two Floras (that of the Eastern Interior, and that of the Gulf of Carpentaria, and of Arnheim' land) to see the flower, the fruit and seed of almost every one.—As my collection increased, I surrounded the different packages with green hide, which when dry, formed a fine box round them, and protected them from the hard usage to which they were exposed (Aurousseau 1968, p. 869).

As supplies dwindled, the loads were substituted with the biological specimens of Leichhardt and Gilbert. In the final stages of the journey the small number of remaining packhorses and bullocks were in poor health and in the last quarter of the journey on the Roper River a disaster struck. Three horses were drowned and then two days later another horse suffered the same fate. Without the means to carry the load, Leichhardt sacrificed the bulk of his plant collection. The loss of the specimens was a great tragedy for Australian botany and very exasperating for the passionate Leichhardt.

This disastrous event staggered me, and for a moment I turned almost giddy; but there was no help. Unable to increase the load of my bullocks, I was obliged to leave that part of my botanical collection which had been carried by one of the horses. The fruit of many a day's work was consigned to the fire; and tears were in my eyes when I saw one of the most interesting results of my expedition vanish into smoke. Mr. Gilbert's small collection of plants, which I had carefully retained hitherto, shared the same fate. But they were of less value, as they were mostly in a bad state of preservation, from being too much crowded. My collection had the great advantage of being almost complete in blossoms, fruit, and seed, which I was enabled to ensure in consequence of the

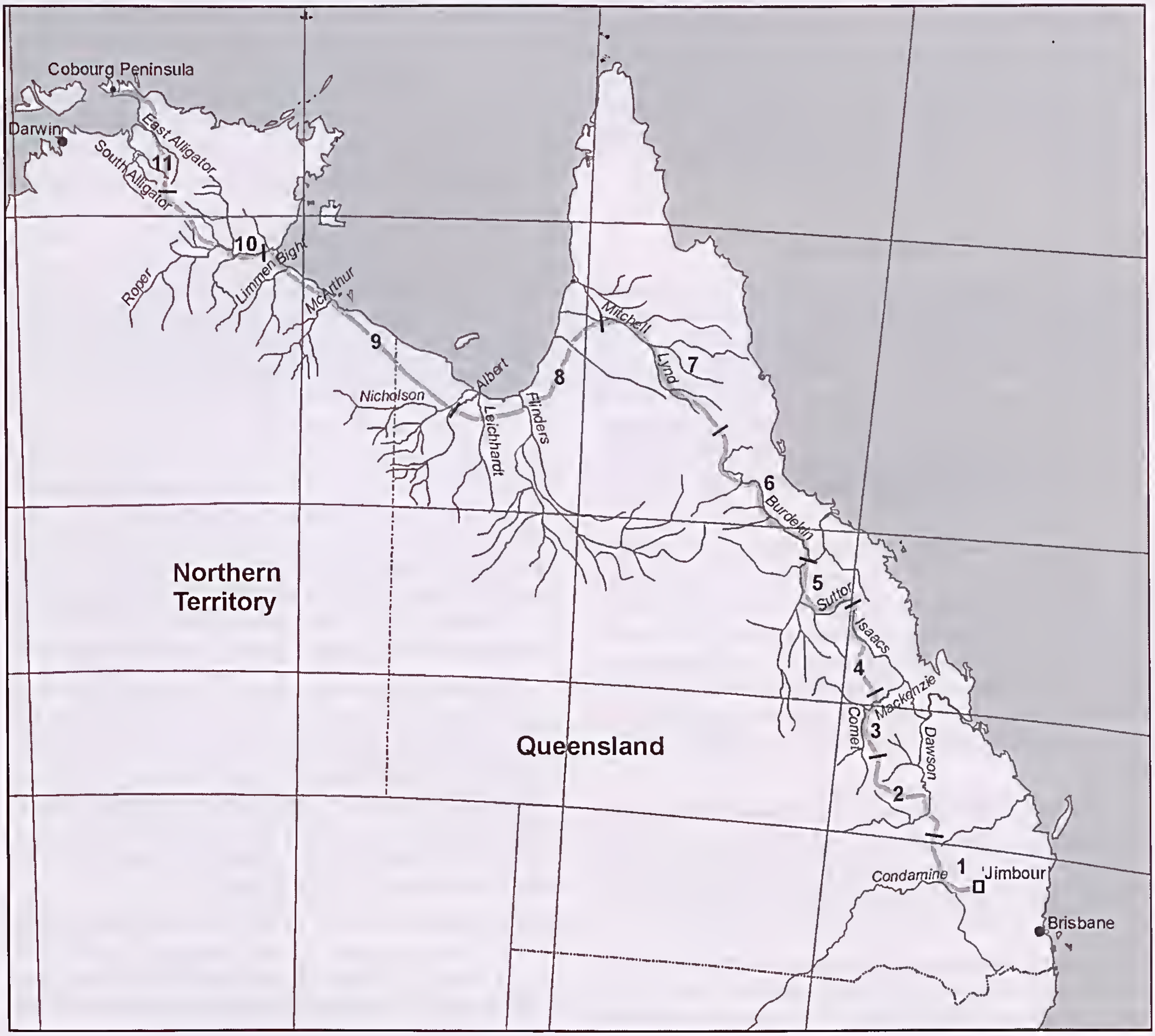


Fig. 1. Route of the Port Essington Expedition with major rivers, current place names and the geographic sections used in this paper identified. The Moreton Bay district is currently the area of south-east Queensland around Brisbane. The journey sections included in the text are 1. Condamine, 2. Dawson, 3. Comet-Mackenzie, 4. Peak Downs-Isaacs, 5. Suttor, 6. Burdekin, 7. Lynd-Mitchell, 8. Eastern Gulf of Carpentaria, 9. Western Gulf of Carpentaria, 10. Arnhem Land plateau, 11. Top End lowlands.

long duration of our expedition, and of the comparative uniformity of the Australian Flora. (Leichhardt 1847a, p. 445)

The letter to Durando gave more heart-wrenching detail.

For the time came, when I had to open all my fine green hide boxes, to make a poor choice of the dried plants, and to throw the greatest number of them away unable to carry them any farther, as 4 of my pack horses drowned, and the means of carrying my collection of plants and geological specimens were consequently destroyed. I fully lost by this 4–5000 specimens (Aurousseau 1968, p. 869–870).

The fate of the remnant collection

Bell (2004) suggested that Leichhardt's collections from the early part of the journey were sent back with Hodgson and Caleb who turned homeward from 'Dried Bullock Creek' on November 4 1844. While it does seem logical that Leichhardt would have sought to offload specimens, we could find no record of such a transaction in any journals of Leichhardt, Gilbert or Hodgson, nor have we located any specimens where the collecting date corresponds with this section of the Port Essington Expedition.

It is clear from Leichhardt's letters (Aurousseau pp. 870, 899, 906, 968, 969, 983, 994) and notebook (Leichhardt 1842–1847; p. 47–48) that some portion of the plant collection from the Port Essington Expedition was retained and sent to Durando in Paris. Durando apparently passed the specimens on to Joseph Decaisne (Muséum d'Histoire Naturelle, Paris) who later reported that Leichhardt's specimens were 'too badly damaged for exact study' (Aurousseau 1968, p. 1064).

Leichhardt requested of his friend Durando that a set of duplicates from his remnant Port Essington Expedition collection be sent back to him in Australia (Aurousseau 1968, p. 906). Durando evidently did send back specimens to Australia, as some now reside in NSW and MEL.

We currently know only of 36 plant specimens from the Port Essington Expedition in Australian herbaria (Table 1). We have also gleaned an additional 16 citations of specimens that may reside in European or Australian herbaria (Table 1). It seems likely that numerous Port Essington Expedition specimens may yet be found in the Paris Herbarium, but as yet there has been limited investigation.

Reconstructing the Botany

Because of the lost specimens the only possible means of reconstructing the botany of the Port Essington Expedition is through the pages of Leichhardt's journal. In this study we have attempted to provide current botanical names for the plant species that Leichhardt described in his journal during the 1844–1845 expedition. This effort to attribute botanical names to the plants recorded in his journal is offered as a small tribute to Leichhardt's largely unrecognised botanical achievements.

We have used the 1847 edition of the Journal from the Port Essington Expedition, edited by Captain Phillip Parker King rather than the journal prepared by Leichhardt on his return to Sydney in 1846, although there appears to have been little editing of the botanical material from the original. References to plants were extracted from the journal, including any information that was useful to assist in the ascription of the plant to a current name including information on habit or habitat and co-occurring species. The current geographical distribution of Queensland plant species, as approximated by the Queensland Herbarium specimen database (HERBRECS), was a particularly useful aid in confirming (or otherwise) the postulated identity of species. There are only a few areas where the authors have revisited Leichhardt's route, so this study is mostly reliant on knowledge of the flora at regional scales. We have used published sources to assist in our determination of species, wherever possible. The journals of Leichhardt's second expedition (Bunce 1979, Sprod 1989) sometimes shed light on species observed during the Port Essington Expedition. Jackes (1990) attempted to identify some of the plants recorded by Leichhardt during a short section of the Port Essington Expedition, near the Mitchell River in north Queensland where John Gilbert was speared. Bell (2004) has ascribed Leichhardt's plant descriptions for the Condamine leg of the journey. Where our ascriptions disagree from these previous studies, a footnote is provided.

The expedition has been divided into 11 geographical sections generally relating to major river catchments or geomorphic units. At the start of each section, a summary description is provided using the context of modern place names with a brief description of the environments or habitats through which the party was travelling. McLaren (1993) was used to determine the route of the Port Essington Expedition and the location and timing of the camp-sites.

Individual plant references in the journal are only ascribed the first time they appear in each geographic section. The journal dates of subsequent references to the same plant are included as footnotes where the plant has been first ascribed in the text. This method considerably reduces the length of this paper, avoiding considerable repetition but allows the reader to readily identify all plant references in the journal at the scale of the geographical section. For example in the Condamine section, 'Bricklow' is ascribed as *Acacia harpophylla* the first time the name appears. There is a footnote at this ascription providing the dates of the 12 subsequent references to 'Bricklow' during that section. This system is applied for each leg, such that Bricklow is reidentified as *Acacia harpophylla* the first time the name appears during other geographic sections with footnotes to the subsequent references to that species during that section. If Leichhardt uses two names for the same species then each of those names are separately ascribed. Where a generic or common name provided by Leichhardt has a different identity at another location we have reinterpreted subsequent uses of the name. For example, he applied the name 'rusty gum' to *Corymbia aureola, C. bleeseri, C. bloxsomei, C. bunites, C. curtipes, C. leichhardtii, C. peltata, C. pocillum, C. terminalis, C. trachyphloia* and *C. watsoniana* at various locations.

Where there is no reasonable doubt as to the identity of a taxon, the contemporary botanical name is provided without qualification. Where there is a minor doubt as to a species identity we preface the identification with 'probably' and where uncertainty is considerable we use the preface 'possibly'. Where ascriptions could refer to more than one taxon, they are ordered from most likely to least likely, but where there are four or more species that could correspond to Leichhardt's reference, only the genus name is given (e.g. *Dodonaea* sp.). We have not ascribed family-level descriptions (e.g. 'chenopodiaceous plants'). We have not generally provided a rationale for our ascriptions as this would have resulted in a considerable expansion of an already lengthy paper. Species nomenclature follows that currently used by the Queensland Herbarium and the Northern Territory Herbarium in 2005.

Table 1. Records of Leichhardt collections that can be unambiguously attributed to the Port Essington Expedition. Collections made at Port Essington after the completion of the journey are excluded. Herbaria cited below are: National Herbarium of Victoria (MEL), National Herbarium of New South Wales (NSW), Natural History Museum of London (BM), Royal Botanic Gardens, Kew (K), and Muséum National d'Histoire Naturelle, Paris (P). The original collecting name is provided in brackets. Specimen searches for the species in the following table has been comprehensive for MEL, NSW, BM and K.

Current Name (Name cited in text reference)	Text reference	Herbarium where specimen is held, date and locality
Acacia alleniana		MEL, undated, Macarthur R Gulf of Carpentaria
Acacia conspersa		NSW, undated, Sterculia Ck, west coast of the Gulf near Limmen Bight
Acacia galioides		MEL, undated, without locality [species not known south of Peak Range]
Acacia simsii	'Also in Leichhardt's collection' Bentham (1864), Fl. Austral. 2: 382	Specimen not located
Acacia subternata		NSW, undated, without locality [species confined to Top End of N.T.]
Alyxia spicata		MEL, undated, without locality [species confined to northern Australia]
Arthrostylis aphylla (*Fimbristylis aphylla*)		MEL, undated, West of the Gulf and Port Essington
Atalaya hemiglauca		NSW, undated, Head of the gulf
Bambusa arnhemica (Bambusa arundinacea)	'from the South Alligator River (Leichhardt)' Mueller (1867), Fragm. 6: 86	Specimen not located
Bruguiera gymnorrhiza	'Port Essington and Limmen Bight river, Leichhardt' Bentham (1864) Fl. Austral. 2: 495	Specimen not located
Cathormion umbellatum (Pithecellobium moniliferum)	'Along all the water courses round the Gulf of Carpentaria, Leichhardt' Bentham (1864), Fl. Austral. 2: 424	Specimen not located
Cordia dichotoma (*Cordia ixiocarpa*)	'In low hills of the Gilbert River, Leichhardt' Mueller (1858), Fragm. 1: 59	Specimen not located
Corymbia dunlopiana		NSW, undated, Overland to Port Essington
Crotalaria cunninghamii		NSW, 1844, West side of the Gulf
Erythrophleum chlorostachys (*Erythrophloeum laboucheri*) (1864), Fl. Austral. 2: 297	'Also in Leichhardt's collection, and said to be his Leguminous Iron-bark tree' Bentham Specimen not located	

Eucalyptus tetrodonta		NSW, undated, West coast of the Gulf
Flemingia parviflora	'Lynedoch [?] valley, Leichhardt' Bentham (1864), Fl. Austral. 2: 269	MEL, undated, Lynd R
Gardenia vilhelmii (*Gardenia edulis*)	'On sunny plains of north-eastern Australia, Leichhardt' Mueller (1858), Fragm. 1: 54	Specimen not located
Grevillea glauca		
		BM, undated, Snowdrops last [camp], Suttor and down to the gulf
Grevillea glauca (*Grevillea gibbosa*)	'Suttor, Cape & Burdekin rivers, Leichhardt' Bentham (1870), Fl. Austral. 5: 463	MEL, undated, first found at the Suttor and frequently along the Burdekin and upper Lynd
Grevillea mimosoides		
		BM, undated, first met at the upper Lynd - all round the Gulf
Grevillea pteridifolia		NSW, 22 May 1845, Burdekin River
Grevillea pungens (*Grevillea leichhardtii*)	'N. Australia, Sandy scrubland west side of gulf [Carpentaria]; Leichhardt' Moore (1920), J. Linn. Soc. Bot. 45: 211 (1920)	BM, K, MEL, 2 October 1845, West coast of the Gulf
Grevillea refracta		NSW, undated, West coast of the Gulf of Carpentaria
Grevillea rubicunda		BM, undated, westward of the Gulf, table-land of South Alligator
Hakea arborescens		BM, undated, Upper Burdekin and Lynd on rocky slopes
Hakea arborescens		BM, undated, West coast of the gulf
Heliotropium tanythrix		MEL, undated, Northern Australia
Ipomoea nil (*Ipomoea hederacea*)	'Queensland. Suttor and Burdekin rivers, Leichhardt' Bentham (1869), Fl. Austral. 4: 417	Specimen not located
Isotoma gulliveri (*Laurentia gulliveri*)		P, undated, Norman and Gilbert rivers
Larsenaikia ochreata (*Gardenia ochreata*)	'at the Isaacs River (Leichhardt)' Mueller (1869), Fragm. 7: 46	MEL, Isaacs River
Laxmannia gracilis		MEL, undated, Carpentaria, east Austr.
Lophostemon grandiflorus		MEL, undated, Gilbert R
Bauhinia cunninghamii (*Bauhinia leichhardtii*)		NSW, The Bauhinia Plains of the Mitchell
Macropteranthes montana (*Lumnitzera montana*)	'at the Lynd River, towards its mouth, Dr. Leichhardt' Mueller (1864), Fragm. 4: 173	MEL, undated, Upper Lynd
Melochia pyramidata		NSW, 1845, Datura camp on the Suttor
Millettia pinnata (*Pongamia pinnata*)		MEL, undated, Mitchell R, Gulf of Carpentaria
Mitrasacme elata		MEL, undated, Tableland of the South Alligator R, #453
Monochoria cyanea (*Limnostachys cyanea*)	'in Arnhem's Land, Leichhardt' Mueller (1858), Fragm. 1: 24. 'at the Burdekin River, Leichhardt' Mueller (1873), Fragm. 8: 44	Specimen not located
Nelumbo nucifera		NSW, 1845, East coast of the Gulf
Olax aphylla	'Arnhem's Land, Leichhardt' Bentham (1863), Fl. Austral. 1: 393 'It was discovered by Leichhardt at the South Alligator River' Mueller (1875), Fragm. 9: 151	Specimen not located

Parinari nonda (*Parinarium nonda*)	'from the Upper Lind to Van Diemen's river, Gulf of Carpentaria, Leichhardt' Bentham (1864), Fl. Austral. 2: 426	MEL, undated, from the upper Lynd to Van Diemen's river
Pogostemon stellatus		MEL, 19 June 1845, round the lagoon, (12 Mile Lagoon) [Mitchell R ?]
Pouzolzia hirta (*Pouzolzia quinquenervis*)	'tableland of South Alligator river and Upper Lind river, Leichhardt' Bentham (1873), Fl. Austral. 6: 187	Specimen not located
Pouzolzia hirta (*Hyrtanandra lythroides*)	'At Lynd's River towards its source, and certainly at the South Alligator on tablelands, Dr. Leichhardt' Mueller (1866), Fragm. 5: 194	Specimen not located
Rhizophora stylosa		MEL, undated, From the mangrove swamps of Limmin Bight. Port Essington, Entrance Is. Port Essington, saltwater
Roepera apiculata		NSW, January 1845, Scrubs of the Comet River
Rotala occultiflora (*Rotala occultiflora* var. *leichhardtii*)	'In the interior of north-eastern Australia, The Lynd (collector Leichhardt, Paris Herbarium)' Koehne (1883), Bot. Jahrb. Syst. 4: 387	MEL, undated, Lagoons of the Lynd and Mitchell (rivers)
Rotala tripartita (*Ammannia pentandra*)	'grows at the Lynd River as already noted by Leichhardt' Mueller (1871), Fragm. 7: 147	Specimen not located
Senna magnifolia		MEL, undated, Northern Australia
Terminalia sp. [undetermined 'little tree' of family Combretaceae]		MEL, 1845, Head of Gulf
Terminalia platyptera	'Lynd river, Leichhardt' Bentham (1864), Fl. Austral. 2: 498	MEL, undated, Lynd River
Tournefortia muelleri		MEL, undated, without locality [species grows around Burdekin River and Top End of N.T.]
Trianthema compacta		MEL, undated, without locality [species grows around Gulf of Carpentaria and Top End of N.T.]
Urena armitiana (*Urena lobata* var. *grandiflora*)	'Suttor and Burdekin rivers, Leichhardt' Bentham (1863), Fl. Austral. 1: 206	K, Burdekin and Suttor Rivers, tropical Australia

Annotated extracts from the Port Essington Expedition (Leichhardt 1847a)

Section 1. Condamine (Late September-November 4 1844)

The party set out from Jimbour in the Darling Downs on October 2 1844 in a generally westerly direction through alternating grassland and open woodlands until they hit dense brigalow scrub to the north-east of Warra. The expedition followed the edge of this scrub in a SW direction to a camp near Warra on October 4. They then travelled downstream along the Condamine and its tributaries avoiding the dense patches of brigalow scrub on the flood plain to a camp about 10km south-west of Chinchilla. The party headed north along tributaries of the Condamine. In places they were confounded by impenetrable brigalow scrub and had to retreat. The expedition made little progress during this section and due to heavy rain, they remained for 8 days at a single camp about 10km WNW of Chinchilla. They then travelled north-west through open mixed eucalypt forest, initially interspersed with patches of brigalow before entering Barakula State Forest on October 22, an area consisting of eucalypt forest with patches of cypress pine, underlain by sandstone. Generally they followed watercourses including Dogwood Creek. In the vicinity of the watershed (the imperceptible Great Dividing Range), they headed in a westerly direction until again striking areas of brigalow scrub at a location about 30km ESE of Wandoan. Here they headed north, remaining in eucalypt woodland and avoiding the scrubs on a section that included a 7-day camp during which they slaughtered a bullock and dried its meat. At this point two members (Hodgson and Caleb) left the expedition and returned to the Darling Downs.

Late September

Belts of open forest land, principally composed of the Box-tree of the Colonists (a species of Eucalyptus) [*Eucalyptus populnea*][1]

…patches of scrub, consisting of several species of Acacias, and of a variety of small trees, appear to be the outposts of the extensive scrubs of the interior. There are particularly three species of Acacias, which bestow a peculiar character on these scrubs: the one is the Myal (A. pendula) [*Acacia pendula*][2]—first seen by Oxley on Liverpool Plains, and afterwards at the Barwan, and which exists in all the western plains between the Barwan and Darling Downs—whose drooping foliage and rich yellow blossoms render it extremely elegant and ornamental. The second, the Acacia of Coxen, resembles the Myal (without its drooping character), its narrow lanceolate phyllodia rather stiff, its yellowish branches erect [*Acacia melvillei*][3]. The third, is the Bricklow Acacia, which seems to be identical with the Rose-wood Acacia of Moreton Bay[4]; the latter, however, is a fine tree, 50 to 60 feet high, whereas the former is either a small tree or a shrub. I could not satisfactorily ascertain the origin of the word Bricklow (Brigaloe, *Gould*), but, as it is well understood and generally adopted by all the squatters between the Severn River and the Boyne, I shall make use of the name. Its long, slightly falcate leaves, being of a silvery green colour [*Acacia harpophylla*][5], give a peculiar character to the forest, where the tree abounds.

October 2

... the native tobacco in blossom [*Nicotiana megalosiphon* or *N. forsteri*].

October 3

…small plains alternate with a flat forest country, slightly timbered; melon-holes; marly concretions, a stiff clayey soil, beautifully grassed: the prevailing timber trees are Bastard box [*Eucalyptus coolabah*][6], the Moreton Bay ash [*Corymbia tessellaris*][7], and the Flooded Gum [*Eucalyptus tereticornis* or *E. camaldulensis*][8].

---

[1] See also October 7, 10

[2] See also October 3, 5, 7, 8, 9, 19, 20

[3] See also October 9

[4] The rose-wood Acacia of Moerton Bay is probably *Acacia harpophylla.* In the Moreton Bay District this species has greener leaves than in the Darling Downs. Hodgson (1846, p. 258) in his diary entry for October 7 refers to the 'rosewood' in reference to *A. harpophylla.* Gilbert (1844–1845) mentioned rosewood (probably referring to *A. harpophylla)* on October 18, October 19 and November 2 in his unpublished manuscript.

[5] See also October 3, 4, 5, 8, 9, 10, 11, 22, 23, 26, 27, November 4

[6] The term 'bastard' was commonly applied to half-barked trees during the nineteenth century, as it was generally supposed that they were derived from hybrids between rough and smooth barked species. Bell (2004) ascribed this to *Eucalyptus populnea.* See also October 9.

[7] See also October 9

[8] See also October 4, 9, 10, 22, 23

... the Loranthus and the Myal [probably *Amyema quandang*][9] in immense bushes; Casuarina [*Casuarina cristata*][10] frequent. In the forest, Ranunculus inundatus [*Ranunculus meristus*]; Eryngium with terete simple leaves, of which the horses are fond [*Eryngium plantagineum*]; Prasophyllum elatum, sweetly scented [probably *Prasophyllum patens*][11]. A new composite with white blossoms, the rays narrow and numerous [possibly *Minuria integerrima*][12].

October 4

... a white Vitex in full blossom[*Eremophila mitchellii*][13]. The flats most richly adorned by flowers of a great variety of colours: the yellow Senecios [probably *Senecio brigalowensis*], scarlet Vetches [possibly *Swainsona* spp.], the large Xeranthemums [*Xerochrysum bracteatum*], several patches of Gnaphalium [*Euchiton sphaericus*][14], white Anthemis-like compositae [possibly *Brachyscome dentata* or *Camptacra barbata*]: the soil is a stiff clay with concretions: melon-holes with rushes [*Juncus* spp.]; the lagoons with reeds [*Phragmites australis*][15].

October 5

A small orange tree, about 5–8' high [*Citrus glauca*], grows either socially or scattered in the open scrub, and a leafless shrub, belonging to the Santalaceae [probably *Anthobolus leptomerioides*], grows in oblong detached low thickets.

October 7

The well-known tracks of Blackfellows are everywhere visible; such as trees recently stripped of their bark, the swellings of the apple-tree [*Angophora floribunda*][16] cut off to make vessels for carrying water, honey cut out, and fresh steps cut in the trees to climb for opossums.

October 8

... the sunshine plant (Mimosa terminalis) [*Neptunia gracilis*][17] was frequent on the black soil; a Swainsonia [*Swainsona* sp.][18]; an Anthericum, with allium leaf and fine large yellow blossoms [*Bulbine alata*]; and another species with small blossoms, (Stypandra) [possibly *Caesia vittata*][19].

October 9

… we saw also some Ironbark trees[*Eucalyptus crebra*][20].

---

[9] Leichhardt seems to be talking about the 'Loranthus' growing as a mistletoe on the 'Myal', because on October 20, he also refers to the 'Loranthus of the Myal'

[10] See also October 11, 19, 23

[11] Leichhardt is probably correct with his generic identification because *Prasophyllum* is often scented. Ground orchids are now extremely rare in these environments and have probably been eradicated by grazing and cultivation. The only *Prasophyllum* specimen at the Queensland Herbarium from the fertile habitats of the Darling Downs is from 'north of Oakey', dated 1969 and identified as *Prasophyllum patens.*

[12] Leichhardt collected *Minuria integerrima* on 'Plains of the Condamine' (specimen at Melbourne Herbarium, undated)

[13] We can be certain about the identity of Leichhardt's *Vitex*. The entry for 11 December 1846 (Sprod 1989, p. 134), on Leichhardt's second expedition stated 'The small tree I called the white Vitex has a 2 capsular seed vessel with polyspermia capsules'. Daniel Bunce's diary entry for January 5 1847 recorded, in the vicinity of Chinchilla '...another very handsome pyramidal-growing tree, which we called white *Vitex*. The leaves were of a lively green, and when rubbed, emitted a strong bitter smell.'(Bunce 1979, p. 114). All of these descriptions are compatible with *Eremophila mitchellii.* The flower shape of *E. mitchellii* is similar to the widely cultivated European species *Vitex agnus-castus*. Furthermore *E. mitchellii* has a current distribution matching the geographic spread of Leichhardt's numerous records of 'Vitex', and it is a common species not otherwise described by Leichhardt. Leichhardt did confuse *Vitex* and *Stenochilus* (a synonym of *Eremophila*) because a reference to *Vitex* in the original handwritten manuscript (held in Mitchell Library) on October 19 was amended to *Stenochilus* in the published journal. See also October 5, 11, 24.

[14] See also October 23

[15] On March 10 1845, Leichhardt refers to the 'Reeds, similar to those of Europe'. There are a number of closely allied taxa in *Phragmites* some of which are cosmopolitan species, common in European wetlands. See also October 7

[16] Bell (2004) ascribed this to *Angophora leiocarpa.*

[17] On February 5, Leichhardt again mentions *Mimosa terminalis*, and in brackets, the sensitive plant.

[18] Bell (2004) ascribed this to *Swainsona galegifolia.*

[19] Bell (2004) ascribed this to *Dianella* sp.

[20] Leichhardt gives a fuller description on October 10: 'An Ironbark tree, with greyish fissured bark and pale-green foliage'. See also October 10, 22, 23, 24, 26, 28, November 4. Bell (2004) ascribed the reference on October 10 to *Angophora floribunda.*

October 10

…Sterculia heterophylla [*Brachychiton populneus* subsp. *populneus*] is pretty frequent amongst the box and flooded gum, ...

Ironbark ridges here and there, with spotted gum [*Corymbia citriodora* subsp. *variegata*][21], with dog-wood (Jacksonia) [*Jacksonia scoparia*][22] on a sandy soil, covered with flint pebbles, diversified the sameness. The grass was beautiful, but the tufts distant; the Ironbark forest was sometimes interspersed with clusters of Acacias [*Acacia* spp.]…

... the forest oak [probably *Allocasuarina luehmannii*] is abundant. Here I first met with Hakea lorea, *R.Br.,* with long terete drooping leaves [*Hakea lorea*] ... and with Grevillea mimosoides, *R.Br.*, also a small tree with very long riband-like leaves of a silvery grey [*Grevillea striata*].

October 11

... we came to a Cypress-pine [*Callitris glaucophylla* or *C. endlicheri*][23] thicket, which formed the outside of a Bricklow scrub. This scrub was, at first, unusually open, and I thought that it would be of little extent; I was, however, very much mistaken: the Bricklow Acacia, Casuarinas and a stunted tea-tree [*Melaleuca bracteata*], formed so impervious a thicket ...

Within the scrub there was a slight elevation, in which sandstone cropped out: it was covered with cypress-pine, and an Acacia, different from the Bricklow [possibly *Acacia tenuinervis*]. The Bottle-tree (Sterculia, remarkable for an enlargement of the stem, about three feet above the ground) [*Brachychiton rupestris*] was observed within the scrub: the white Vitex (?) and Geigera *Schott.,* a small tree, with aromatic linear-lanceolate leaves [*Geijera parviflora*] ...

Fusanus, a small tree with pinnate leaves [*Owenia acidula*][24], and Buttneria, a small shrub [probably *Keraudrenia collina*][25], were also found in these groves.

October 19

On a botanical excursion I found a new Loranthus, with flat linear leaves [*Lysiana exocarpi* subsp. *tenuis*], on Casuarina [probably *Allocasuarina luehmannii*][26], a new species of Scaevola [*Scaevola spinescens*][27], Buttneria, and three species of Solanum [*Solanum* spp.][28]. Mr Hodgson brought a shrubby Goodenia [*Goodenia grandiflora*]; another species with linear leaves, and with very small yellow blossoms, growing in moist places in the forest [*Goodenia gracilis* or *G. delicata*]; two shrubby Compositae; three different species of Dodonaea [*Dodonaea* spp.][29], entering into fruit; and a Stenochilus, *R.Br.* with red blossoms, the most common little shrub of the forest [probably *Prostanthera cryptandroides* subsp. *euphrasioides*][30].

October 20

A bright yellow everlasting is very fine and frequent [possibly *Chrysocephalum apiculatum*].

---

[21] See also October 24

[22] See also October 22, 23

[23] See also October 11, 22, 24, 25, 28, November 3, 4

[24] *Fusanus* is a synonym of *Santalum*, which however does not have pinnate leaves. Leichhardt refers to 'Fusanus' again on October 26, '…its fruit (of the size of a small apple), when entirely ripe and dropped from the tree, furnished a very agreeable repast; the rind, however, which surrounds its large rough kernel, is very thin'. These characters confirm Mueller's opinion (in Fragm. 3: 14) that Leichhardt's 'Fusanus' is referable to his *Owenia acidula*.

[25] Bell (2004) ascribed this to *Rulingia* sp. See also October 19

[26] See also October 23

[27] See also October 22

[28] Bell (2004) ascribed this reference to *Solanum esuriale*, *S. semiarmatum* and *S. stelligerum*

[29] See also October 23.

[30] This is ascribed to *Eremophila longifolia* in Bell (2004), probably influenced by the fact that *Stenochilus* is a synonym of *Eremophila*. However, *E. longifolia* is a tall shrub and is not locally common in that area. *Prostanthera cryptandroides* subsp. *euphrasioides* is a small shrub common in the area, and has a flower shape akin to *Eremophila*, but its usual purple flower colour does not match Leichhardt's description. '*Prostanthera* from Hodgsons Creek' is listed under an entry 'Plants of my Expedition' in Leichhardt's (1842–1847, p. 42) notebook and this location coincides with the October 19 journal entry and almost certainly coincides with his *Stenochilus*.

October 22

... a species of Dampiera, with many blue flowers [*Dampiera stricta* or *D. adpressa*], which deserves the name of D. floribunda; here also were Leptospermum [*Leptospermum polygalifolium*]; Persoonia with lanceolate pubescent leaf [*Persoonia sericea*]; Jacksonia (Dogwood); the cypress-pine with a light amber-coloured resin (Charley brought me fine claret-coloured resin, and I should not be surprised to find that it belongs to a different species of Callitris)[31]; an Acacia with glaucous lanceolate one-inch-long phyllodia [*Acacia semilunata*]; and a Daviesia [*Daviesia* sp.][32]; another Acacia with glaucous bipinnate leaves [probably *Acacia spectabilis*]; a white Scaevola, Anthericum [possibly *Arthropodium strictum*][33], and a little Sida, with very showy blossoms [*Sida* sp.].

October 23

A new gum tree, with a rusty-coloured scaly bark [*Corymbia bloxsomei* or *C. watsoniana*], the texture of which, as well as the seed-vessel and the leaf, resembled bloodwood, but specifically different; the apple-tree (Angophora lanceolata) [*Angophora leiocarpa*]; the flooded gum; a Hakea with red blossoms [*Hakea purpurea*]; Zieria [*Zieria aspalathoides*]; Dodonaea; a crassulaceous plant with handsome pink flowers [*Calandrinia balonensis*]; a new myrtaceous tree of irregular stunted growth, about 30 feet high, with linear leaves, similar to those of the rosemary [*Lysicarpus angustifolius*][34]; a stiff grass, peculiar to sandstone regions [probably *Triodia scariosa, T. marginata* or *T. mitchellii*]; and a fine Brunonia with its chaste blue blossoms [*Brunonia australis*][35], ...

... scattered tufts of Anthistiria [*Themeda triandra*][36], and the first appearance of the small grass-tree (Xanthorrhoea) [*Xanthorrhoea johnsonii*] ... narrow-leaved Kennedyas [probably *Hardenbergia violacea*], Gnaphalium in abundance; Aotus [*Aotus subglauca*] in low bushes.

October 24

Several Epacridaceous shrubs and species of Bossiaea [*Bossiaea brownii* or *B. rhombifolia* subsp. *concolor*] and Daviesia reminded me of the flora of the southern districts.

October 25

An Acacia with spiny phyllodia, the lower half attached to the stem, the upper bent off in the form of an open hook [*Acacia triptera*], had been observed by me on the sandstone ridges of Liverpool Plains: and the *tout ensemble* reminded me forcibly of that locality. The cypress-pine, several species of Melaleuca [possibly *Melaleuca decora, M. nodosa* and *M. uncinata*], and a fine ironbark, with broad lanceolate, but not cordate, glaucous leaves, and very dark bark [*Eucalyptus fibrosa* subsp. *nubila*], formed a forest. An arborescent Acacia, in dense thickets [possibly *Acacia shirleyi*], intercepted our course several times.

November 3

A Goodenoviaceous shrub [*Goodenia grandiflora*], a pink Hibiscus [*Hibiscus sturtii*][37], and a fine prostrate Sida [*Sida* sp.], were found between the camp of the 27th October and Dried-beef Creek.

---

[31] Both *Callitris glaucophylla* and *C. endlicheri* occur in the area. Both typically have yellow resin, but both red and yellow resin can occur on the different parts of individual trees (G. Alsemgeest pers. comm.)

[32] See also October 24

[33] Bell (2004) ascribe this reference to *Bulbine alata.* However on the poor soils in the Barakula area, *Arthropodium milleflorum* or *A. strictum* are more likely.

[34] See also October 25

[35] See also October 28

[36] Bell (2004) ascribed this to *Themeda avenacea*, but that species is largely confined to heavy clay soils in this area.

[37] On December 25 1846 during the second expedition Leichhardt 'a fine but low pink hibiscus…were found, as formerly' in about the same location (Sprod 1989, p. 139)

Section 2. Dawson (November 5-December 10 1844)

Now north of the Great Dividing Range they travelled WNW down Roche Creek passing about 12km north of Wandoan before heading north along Juandah Creek to its junction with the Dawson River. This was just to the south of Taroom, which they passed on November 12. The vegetation included open woodlands with patches of brigalow scrub (that were assiduously avoided) on the creek-flat, and ironbark woodland on the low ridges. The latter were often favoured for travelling, taking them in places some distances from the watercourses. The party followed along the broad floodplain of the Dawson River until the density of the brigalow scrubs resulted in a decision to leave the Dawson near its junction with Palm Tree Creek. The party travelled north along Palm Tree Creek then west along Robinson Creek. In places the creek-side vegetation included dense areas of fan-palms sometimes in moderately deep gullies constrained by rugged sandstone hills. In places they camped beside lagoons (i.e. Ropers Lakes and Lake Murphy named after members of the expedition) on the broad flat flood-plain, but in other areas they searched for a route that avoided the dense brigalow scrubs there. The party entered the rugged sandstone country at the southern end of the Expedition Range, skirting to the east of Robinson Gorge National Park (now part of Expedition NP). Initially their route generally followed the upper reaches of Robinson Creek, sometimes along the flats, but more usually picking higher ground. In places the rugged terrain typical of this area hampered travel. After leaving Robinson Creek, travel was generally in a northerly direction until they encountered Ruined Castle Creek flowing NNW, which they loosely followed before traversing some ridges into Comely Creek (Leichhardt's Zamia Creek), which they followed in a northerly direction west of Palmgrove National Park. The expedition was now traversing eucalypt woodland on relatively flat land to the east of the Expedition Range. Before long they headed westward up Erythrina Creek setting up a 3-day camp while Leichhardt searched for a route over the range. The difficult crossing of the rugged Expedition Range was accomplished and the party descended on its western side to the north of Arcadia Valley about 10km south of the Dawson Highway.

November 5

... a considerable creek flowing to the westward, bounded by extensive flooded gum [*Eucalyptus camaldulensis* or *E. tereticornis*][38]-flats and ridges, clothed with a forest of silver-leaved Ironbark [*Eucalyptus melanophloia*][39]. Large reedy [*Phragmites australis*][40] lagoons…

November 6

Fine box [*Eucalyptus populnea*][41] and apple-tree [*Angophora floribunda*][42] flats were on both sides of the creek…

…several plains, with the soil and the vegetation of the Downs, but bounded on the northward by impenetrable Bricklow [*Acacia harpophylla*][43] scrub.

... we passed over open ridges, covered with Bastard-box [*Eucalyptus orgadophila*][44] and silver-leaved Ironbark: the former tree grows generally in rich black soil, which appeared several times in the form of ploughed land, well known, in other parts of the colony, either under that name, or under that of 'Devil-devil land,' as the natives believe it to be the work of an evil spirit.

November 7

… the valley from two to three miles broad, clothed with rich grass, and sprinkled with apple-tree, flooded-gum, and Bastard-box [*Eucalyptus coolabah*][45]

A Thysanotus [*Thysanotus tuberosus*] with fine large blossoms ... The native carrot [*Daucus glochidiatus*][46] is in seed; the Eryngium of Jimba [*Eryngium plantagineum*], and a leguminous plant, prostrate with ternate leaves and bunches of yellow flowers [*Rhynchosia minima*], were frequent; several beautiful species of everlastings were occasionally seen, and the little orange-tree of the Condamine [*Citrus glauca*][47] grew in the scrub.

---

[38] See also November 7, 17, 19, 20, 27, 30, December 7, 9, 10

[39] See also November 6, 7, 14, 20, 27, 30, December 1, 7, 8, 9

[40] See also November 7, 17, 19, 20, 30, December 5, 9

[41] See also December 7, 9

[42] See also November 7, 20, 27, 30

[43] See also November 10, 14, 17, 20, December 1, 8, 10

[44] See also November 7, 20

[45] See also November 8, 10, 20

[46] See also December 8

[47] See also November 20

November 10

The open forest was sometimes one large field of everlasting flowers with bright yellow blossoms; whilst the scrub plains were thickly covered with grasses and vervain [*Verbena gaudichaudii*][48].

... a species of Bauhinia, either shrubby or a small shady tree, with spreading branches; the pods are flat, of a blunt form, almost one inch in breadth, and from three to four inches long [*Bauhina carronii*][49]. The Bricklow seems to prevent the growth of almost all other vegetation, with the exception of a small shrub, linear lanceolate aromatic leaves [probably *Eremophila deserti*]. An Acacia, with long drooping, almost terete leaves [*Acacia stenophylla*][50], grew along the river; and Crinums [*Crinum flaccidum*] grew in patches amongst the everlasting flowers, on a sandy soil.

...strange forms of the Bottle-tree [*Brachychiton rupestris*][51]; which imparted to the scene a very picturesque character.

... that part of the river where it commences to run, its bed was more confined, and was fringed by Melaleucas [*Melaleuca trichostachya*] [52] and drooping Acacias.

November 14

... a creek with Corypha palms [*Livistona nitida*][53], growing to the height of 25 or 30 feet.

.. the hills are more open, and the vegetation composed of the silver-leaved and narrow-leaved Ironbark [*Eucalyptus crebra*][54] trees and an open Vitex [*Eremophila mitchellii*][55] scrub.

November 17

... the fine waterhole ... not only shaded by stately Coryphas and flooded gums, but the drooping Callistemon [*Callistemon viminalis*], the creek Melaleuca, and the Casuarina [*Casuarina cunninghamiana*][56].

... plains ... composed of black soil ... and densely covered with Burr, (a composite plant) [*Calotis* sp.][57] and Verbena, and scattered tufts either of Bricklow, or of Coxen's Acacia [*Acacia melvillei*] or of the bright green Fusanus, or of the darker verdure of Bauhinia, with here and there a solitary tree of a rich dark-green hue, from forty to fifty feet in height [*Cadellia pentastylis*].

The fat-hen (Atriplex) [probably *Atriplex muelleri*][58] and the sow-thistle (Sonchus) [*Sonchus hydrophilus*][59] grew abundantly on the reedy flats at the upper end of the creek; Grewia [*Grewia latifolia*], a prostrate Myoporum [*Eremophila debilis*], and a bean with yellow blossoms [probably *Vigna* sp.] were frequent all over the valley...

In the vicinity of the swamps of Palm-tree Creek, I noticed a grass with an ear much resembling the bearded wheat: with the exception of the cultivated Cerealia, it had the largest seed I ever met with in grasses [probably *Chionachne hubbardiana*][60]; even my Blackfellow was astonished at its remarkable size.

---

[48] Leichhardt used both vervain and verbena to refer to the genus *Verbena* of which *V. gaudichaudii* is common in central Queensland. See also November 17, December 10

[49] See also November 10, 17

[50] See also November 10

[51] See also November 25, December 1, 10

[52] See also November 17, 25

[53] See also November 17, 25, 29, December 1, 9

[54] See also November 25

[55] See also November 20, December 8

[56] See also November 29, December 1, 7, 9

[57] See also November 20, December 10

[58] See also November 17, 19

[59] See also November 17, December 9, 10

[60] Bentham, in Flora Australiensis, cited a specimen of *Chionachne hubbardiana* collected by Leichhardt from the 'Dawson & Comet Rivers'

November 20

... a species of Sterculia grows to a large size, and is one of the most pleasing and ornamental trees of the country; it is probably different from, although nearly allied to S. heterophylla [probably *Brachychiton populneus* subsp. *trilobus*][61]. Very disagreeable, however, was the abundance of Burr and of a spear–grass (Aristida) [*Aristida* sp.], which attached themselves to our clothes and blankets, and entered (particularly the latter) into the very skin. I have also to mention, that a yellow Villarsia [*Nymphoides crenata*] was found on one of the lakes; which were generally surrounded by high sedges.

November 25

The range was openly timbered with white-gum [possibly *Eucalyptus chloroclada*], spotted-gum [*Corymbia citriodora* subsp. *variegata*][62], Ironbark, rusty-gum [*Corymbia bunites* or *C. watsoniana*], and the cypress-pine [*Callitris glaucophylla*][63] near the gullies; and with a little dioecious tree belonging to the Euphorbiaceae ... the 'Severn Tree': it had a yellow or red three-capsular fruit, with a thin fleshy pericarp, of an exceedingly bitter taste; the capsules were one-seeded [*Petalostigma pubescens*].

Pomaderris [*Alphitonia excelsa*] and Flindersia [*Flindersia australis*] were in fruit and blossom.

... the continuation of the range, which I found to be of a flat, sandy, and rotten character, having, with the exception of the Blackbutt, all the trees and other characteristics of the sandstone country of Moreton Bay: Xylomelum [*Xylomelum cunninghamianum*][64], Xanthorrhoea [*Xanthorrhoea johnsonii*], Zamia [*Macrozamia fearnsidei*], Leptospermum [*Leptospermum lamellatum, L. polygalifolium* or *L. sericatum*], a new species of forest oak, which deserves the name of Casuarina villosa, for its bark looks quite villous [*Allocasuarina inophloia*]; Persoonia falcata, *R.Br.,* a small tree about fifteen feet high with stiff glaucous falcate leaves, and racemose inflorescence [*Persoonia falcata*]; a dwarf Persoonia, with linear leaves [*Persoonia subtilis*], the stringy-bark [probably *Eucalyptus mediocris*], and a species of Melaleuca along the creek [*Melaleuca trichostachya*].

November 27

… ascended the range, … covered with open forest, interspersed with thickets of Acacias [probably *Acacia catenulata* or *A. shirleyi*] and Casuarinas [probably *Allocasuarina torulosa*].

November 28

... a new species of Dodonaea, with pinnate pubescent leaves [*Dodonaea vestita*], was frequent.

November 30

… sandy slopes covered with Dogwood (Jacksonia) [*Jacksonia scoparia*] and spotted-gum.

December 1

…an oak-tree [*Casuarina cunninghamiana*] creek,

... the blady-grass [*Imperata cylindrica*], however, had begun to shew its young shoots, ...

... a prickly Acacia with pinnate leaves [probably *Acacia farnesiana*], much resembling the A. farnesiana of Darling Downs.

... an arborescent Zamia, with a stem from seven to eight or ten feet high, and about nine inches in diameter [*Macrozamia moorei*][65], ...

... I was surprised to find Erythrina [*Erythrina vespertilio*][66], which I had been accustomed to meet with only on the creeks, and at the outskirts of mountain brushes, near the sea-coast. The white cedar (Melia Azedarach) [*Melia azedarach*] grows also along Zamia Creek, with casuarina, and a species of Leptospermum [*Leptospermum polygalifolium*].

---

[61] See also November 20, December 1

[62] See also November 30, December 1

[63] See also November 28, December 1

[64] The species growing around Moreton Bay is *X. salicinum*

[65] See also December 9, 10

[66] See also December 9, 10

December 3

In the rocky gullies, we found the following plants: a new species of Grevillea, having pinnatifid leaves with very long divisions, the blossoms of a fine red, and the seed-vessels containing two flat seeds, surrounded by a narrow transparent membrane [*Grevillea longistyla*]; Leucopogon juniperinum and lanceolatum [*Acrotriche aggregata, Leucopogon* sp. or *Monotoca scoparia*] a Dodonaea with long linear leaves [*Dodonaea filifolia* or *D. viscosa* subsp. *angustissima*] and D. triquetra [*Dodonaea viscosa* subsp. *spatulata*], were frequent.

December 9

The forest was well grassed; and a small Acacia, about fifteen or twenty feet high, with light green bipinnate leaves (from which exuded an amber-coloured eatable gum) [*Acacia bidwillii*][67] formed groves and thickets within it. A Capparis, a small stunted tree, was in fruit: this fruit is about one inch long and three-quarters of an inch broad, pear-shaped and smooth, with some irregular prominent lines [probably *Capparis loranthifolia* var. *loranthifolia*]. Capparis mitchelii [*Capparis mitchellii*] has a *downy* fruit, and is common in the scrubs. A small trailing Capparis, also with oblong eatable fruit [*Capparis lasiantha*] was first observed on a hill near Ruined Castle Creek, in lat. 25⁰ 10': we met with it frequently afterwards. We were encamped in the shade of a fine Erythrina; and the Corypha-palm, Tristania [*Lophostemon suaveolens*][68], the flooded-gum, the silver-leaved Ironbark, Tripetelus [probably *Sambucus gaudichaudiana*], and a species of Croton [*Croton insularis* or *C. phebalioides*][69], grew around us. A species of Hypochaeris [possibly *Picris angustifolia* subsp. *carolorum-henricorum*] and of Sonchus, were greedily eaten by our horses; the large Xeranthemum [*Xerochrysum bracteatum*] grew on the slopes, among high tufts of kangaroo grass. A species of Borage (Trichodesma zeylanica), with fine blue flowers [*Trichodesma zeylanicum*], was first seen here; and the native raspberry [*Rubus parvifolius*] and Ficus muntia [*Ficus coronata*], were in fruit.

December 10

The gully had all the characters of those of the Boyd; the same sandstone rock, the same abruptness, and the same vegetation; excepting, perhaps, a new Grevillea, with pinnatifid leaves and yellowish-white woolly flowers [*Grevillea sessilis*][70], which we found here.

… we found that the gullies opened into a broad flat valley; in which fields of fat-hen, the Croton shrub, the native Tobacco [*Nicotiana megalosiphon* or *N. forsteri*], Erythrina, fine specimens of flooded-gum, Tristania, and the Moreton Bay ash [*Corymbia tessellaris*], were growing in great abundance.

In crossing several of the scrub plains before mentioned, it was agreeable to observe that the dense vegetation which covered them was not the miserable Burr and the wiry Vervain, but Senecios [probably *Senecio brigalowensis*] and Sonchus (Sowthistle), which our horses greedily snatched as they waded through them…

In the gully which I descended, a shrub with dark-green leaves was tolerably frequent; its red berries, containing one or two seeds, were about the size of a cherry, and very good eating when ripe [probably *Erythroxylum australe*].

... a species of Clematis [*Clematis glycinoides* or *C. microphylla*] tied the shrubs into an almost impenetrable maze.

---

[67] Leichhardt later referred to this species, on several occasions, as the 'Acacia of the Expedition Range'. The range of locations mentioned for this species is consistent with the known range of *Acacia bidwillii.*

[68] See also December 10

[69] See also December 10

[70] See also December 10

Section 3. Comet-McKenzie (December 11 1844-January 17 1845)

On the western side of the Expedition Range the party travelled in a westerly direction, over predominantly level terrain, sometimes traversing areas of brigalow scrub and in other places avoiding them by following watercourses. At one point they headed south searching for lost party members and camped for several days by a lagoon (probably Pink Lily Lagoon). A watercourse they followed led them to the Comet River, which they followed downstream to reach Rolleston on December 28. In this vicinity, the party witnessed the first expanses of well-grassed country since they had left the Darling Downs. Leichhardt named this area 'Albinia Downs', which now includes Albinia Downs NP. The party was heading north picking a suitable route generally following the Comet River downstream. In places the brigalow scrubs provided a barrier, although grasslands and woodlands on basalt away from the floodplain allowed easy travel. They followed the Comet River north until it met the Mackenzie River about 5km north of the town of Comet on the Capricorn Highway. They followed the Mackenzie River to the northeast generally staying within the floodplain until a point about 30km ENE of Comet where they camped for several days.

December 14

The Myal [*Acacia pendula*][71] was frequent; and the fruit of the small lemon-tree [*Citrus glauca*][72] was ripe.

I followed the watercourse which connects the water-holes on which we encamped, and met every where with Bricklow [*Acacia harpophylla*][73] scrub.

December 15

The Box-tree of Jimba-flats [*Eucalyptus populnea*][74], the Bricklow — in short, the whole vegetation of the scrubby country, west of Darling Downs, were still around us; and the Moreton Bay ash [*Corymbia tessellaris*] (a species of Eucalyptus) — which I had met with, throughout the Moreton Bay district, from the sea coast of the Nynga Nyngas to Darling Downs — was here also very plentiful.

December 16

… found the creek, with a deep sandy, but dry bed, full of reeds [*Phragmites australis*][75]…

I looked into the Casuarina [*Casuarina cunninghamiana*][76] thickets which occasionally fringed its bank, in search of water; but found none.

The country appeared flat, and was so openly timbered with fine flooded gum-trees [*Eucalyptus camaldulensis* or *E. tereticornis*][77], that we could see for a considerable distance.

The chains of water-holes within the scrub are covered with a stiff star-grass, having a great number of spikes rising from the top of the stem [*Leptochloa digitata*][78].

A stiff, wiry, leafless polygonaceous plant [*Muehlenbeckia florulenta*] grows in the shallow depressions of the surface of the ground, which are significantly termed by the squatters 'Melon-holes', and abound in the open Box-tree flats.

A small shrubby Stenochilus with very green linear lanceolate leaves and red tubulous flowers [*Eremophila maculata*], is frequent amongst the Bricklow.

December 20

Capparis Mitchelii [*Capparis mitchellii*] was found in blossom.

---

[71] See also December 24

[72] See also December 16, 22, 24

[73] See also December 15, 16, 19, 22, 24, 28, 31, January 3

[74] Sometimes Leichhardt refered to this species as 'true box'. See also December 16, 22, 23, 28, 30, January 1, 3, 4

[75] See also December 16, 21, 31

[76] See also December 28, January 6

[77] See also January 6

[78] See also December 24, January 4

December 21

... a beautiful blue Nymphaea [probably *Nymphaea gigantea*][79] was found growing in the lagoon; and around it, among the reeds and high cyperaceous plants, a small labiate [probably *Basilicum polystachyon*], a Gomphrena [probably *Alternanthera* sp.], the native Chamomile, and a Bellis [possibly *Brachyscome basaltica*] were growing.

December 22

...farther on, the Bastard box [probably *Eucalyptus orgadophila*][80] prevailed, with silver-leaved Ironbark [*Eucalyptus melanophloia*][81], and patches of Bricklow scrub, of Vitex [*Eremophila mitchellii*][82] and of the native lemon. A small tree (a species of Acacia) was also seen about thirty or forty feet high, with slightly drooping branches, and lanceolate deep green phyllodia about one inch [*Acacia excelsa*][83].

December 23

The principal channel of the creek was lined with a species of Melaleuca, with slightly foliacious bark [*Melaleuca* sp.].

December 27

Mr Calvert found a Bauhinia [*Bauhinia carronii*] in blossom; which was not only different from the Bauhinia found afterwards at Comet River, but also from that of the Mitchell.

December 29

We observed growing on the creek, the dwarf Koorajong (Grewia) [probably *Grewia latifolia*], a small rough-leaved fig tree [*Ficus opposita*], a species of Tribulus [*Tribulus terrestris* or *T. minutus*], and the native Portulaca [*Portulaca oleracea*][84]. The latter afforded us an excellent salad; but was much more acid than I had found it in other parts of the country, where I had occasionally tasted it. The native melon [*Cucumis melo*] of the Darling Downs and of the Gwyder,grew here also.

December 30

A pea-plant, with ternate leaves, and fine yellow blossoms [*Rhynchosia minima*], was found near our camp.

The bronze-winged pigeon lived here on the red fruit of the Rhagodia [*Enchylaena tomentosa*] probably, and the black berries of a species of Jasmine [*Jasminum didymum, J. suavissimum* or *J. simplicifolium*]; and seems also to pick occasionally the seed vessel of a Ruellia [probably *Dipteracanthus australasicus* subsp. *corynothecus*], which is very frequent on all the flats of Comet Creek.

December 31

The immediate neighbourhood of the creek was in some places open, in others covered with a shrubby Acacia, with long glaucous, and rather fleshy phyllodia [*Acacia salicina*].

Yesterday we met with a new leguminous shrub. It belongs to the section Cassia, and has a long pinnate leaf, the leaflets an inch long, and half an inch broad. Its pods were about a foot long, half an inch broad; and every seed was surrounded by a fleshy spongy tissue, which, when dry, gave to the pod a slightly articulate appearance [*Cassia brewsteri*][85]. The seeds, when young, had an agreeable taste, and the tissue, when dry, was pleasantly acidulous, and was eaten by some of my companions without any ill effect, whilst others, with myself, were severely purged. To day I found the same plant in form of a tree, about thirty feet high...

January 1, 1845

I found a red Passion flower, with three-lobed leaves, the lobes rounded [*Passiflora aurantia*]: it was twining round the trunk of a gum tree, and rooted in a light sandy alluvial soil. A new species of Bauhinia, with large white blossoms growing in small groves, or scattered in the scrub, particularly near the creeks, was conspicuous for its elegance, and was the greatest ornament of this part of the country. It is a tree about twenty-five feet high, with long drooping branches; the foliage is of a rich green colour, and affords a fine shade [*Bauhinia hookeri*]. A climbing Capparis, with broad lanceolate leaves, had also large white showy blossoms [*Capparis lasiantha*]; and a fine specimen of this plant was seen growing in the fork of an old box tree, about twelve or fifteen feet from the ground; it was in fruit, but unfortunately was not yet ripe. There was also another species of the same genus, with yellow blossoms, in other respects very similar in appearance to the first [*Capparis lasiantha*]. The white cedar [*Melia azedarach*] was still abundant.

---

[79] See also January 10
[80] See also January 14
[81] See also December 23, January 4, 14
[82] See also January 3
[83] See also January 14
[84] See also December 30
[85] See also January 10

January 2

I moved my camp to the water-hole, near which I had met with the natives, and halted at the outside of a Bauhinia [*Bauhinia carronii* or *B. hookeri*] grove.

January 3

I noticed a small tree (Santalum oblongatum, *R.Br.*), very remarkable for having its branches sometimes slightly drooping, and at other times erect, with membranous glaucous elliptical leaves, from an inch to an inch and a half long, and three-quarters broad, with very indistinct nerves, and producing a small purple fruit [*Santalum lanceolatum*][86], of very agreeable taste. I had seen this tree formerly at the Gwyder, and in the rosewood scrubs about Moreton Bay, and I also found it far up to the northward, in the moderately open Vitex and Bricklow scrubs.

January 4

In the channels within the scrub I found a large supply of water, in holes surrounded by sedges and a broad-leaved Polygonum [probably *Persicaria orientalis*], amongst which grew a species of Abutilon [*Abutilon* sp.] ... In the scrub I found a plant belonging to the Amaryllideae (Calostemma luteum?) with a cluster of fine yellow blossoms [*Calostemma luteum*].

January 5

Marsilea [*Marsilea* sp.] grows everywhere on the flats; and a fine little pea plant with a solitary red blossom [probably *Indigofera linifolia*], was found amongst the basaltic rocks round the water-hole. We observed, growing along the creek, another species of Portulaca, with linear fleshy leaves, erect stem, and small yellow flowers [*Portulaca filifolia* or *P. australis*] and a half-shrubby Malvaceous plant, with small clustered yellow blossoms [*Sida subspicata*]: the latter is common at the outside of scrubs in the Moreton Bay district. We also remarked, within the scrub, a small tree, with bright-green foliage, and three-winged capsules slightly united at the base [possibly *Terminalia oblongata*][87]; and another small tree, with deep green coloured leaves, and two-winged capsules united in all their length; the last is nearly allied to Dodonaea [possibly *Dodonaea viscosa*][88].

January 7

..well-watered country, but still occupied by scrub; in which the Capparis, with its large white sweet-scented blossoms, was very frequent; but its sepals, petals, and stamens dropped off at the slightest touch. Its fruit was like a small apple covered with warts, and its pungent seeds were imbedded in a yellow pulp [*Capparis loranthifolia* var. *bancroftii*], not at all disagreeable to eat.

---

[86] In a letter to Captain P.P. King on 12 August 1846, Leichhardt noted 'Santalum lanceolatum with blue edible berries was only observed on the East coast'. (Aurousseau 1968, p. 889)

[87] This reference and the following seem confused. *Terminalia oblongata* is a common species that coincides approximately with this locality, but has a two-winged seed

[88] This reference and the previous seem confused. *Dodonaea* has two or three-winged capsules and should be known to Leichhardt. On the second expedition in the same vicinity he identified 'the sapindaceous (?) tree with bright green leaf forms rather an open scrub'. (February 28 1847, p. 176), and then later, 'The green tree with winged seed which is thought as belonging to the sapindaceae has one straight embryo and belongs probably to the Acerineae' (February 28 1847, Sprod 1989, p. 176). Bunce, a member of Leichhardt's second expedition, referred to *Dodonaea* around this locality (February 20 1847, p. 141 and March 1 1847, p. 143 Bunce 1979). These references seem compatible with *Dodonaea* of which only *D. viscosa* is common in this area

January 9

…we encountered sandy hills covered with a dense low scrub and cypress-pine [*Callitris glaucophylla*][89]. The latter almost invariably grows on the slight sandstone elevations in a scrubby country.

January 10

A very stiff high grass [possibly *Arundinella nepalensis*] became very general along the river. On the plains there were fields of native carrots, now dry; also of vervain [*Verbena gaudichaudii*] and burr [*Calotis* sp.].

January 12

The Acacia, with very long linear drooping leaves [*Acacia stenophylla*], that had been observed at the Dawson, re-appeared both on Comet Creek and the banks of the Mackenzie.

January 13

I observed a new species of Flindersia, a small tree about thirty feet high, with thin foliage and very regular branches, forming a spire [*Flindersia dissosperma*][90].

January 14

In the bed of the river, which was here broad and sandy, a bean was gathered, bearing racemes of pink blossoms, and spreading its long slender stem over the ground or twining it round shrubs or trees: its pods were from three to five inches long, and about half an inch broad, containing from four to six seeds, very similar to the horse-bean [*Canavalia papuana*]. This plant was afterwards found growing in the sandy beds, or along the bergs of almost all the broad rivers, and was always a welcome sight; for the seeds, after roasting and pounding them, afforded us a very agreeable substitute for coffee.

We passed over some very fine flats of Bastard-box [*Eucalyptus coolabah*], silver-leaved Ironbark, and white gum [probably *Eucalyptus tereticornis*][91]…

On a White-gum, which has long lanceolate leaves, I found a species of Loranthus, with leaves resembling those of the silver-leaved Ironbark (Eucalyptus pulverulentus) [*Dendrophthoe homoplastica*]…

January 16

…came to some fine lagoons, which were surrounded by a deep green belt of Nelumbiums [*Nelumbo nucifera*][92]. This plant grows, with a simple tap root, in the deep soft mud, bearing one large peltate leaf on a leaf stalk, about eight feet high, and from twelve to eighteen inches in diameter, the flower-stalk being of the same length or even longer, crowned with a pink flower resembling that of a Nymphaea, but much larger: its seed-vessel is a large cone, with perpendicular holes in its cellular tissue, containing seeds, about three quarters of an inch in length.

Section 4. Peak Downs-Isaacs (January 18-March 7 1845)

Leaving the Mackenzie River they travelled generally NW over sandstone ridges avoiding occasional brigalow scrubs on the flats but following dry watercourses in search of water holes. On January 28 they camped near Mt Demipique, the southernmost peak of the Peak Ranges, 35km NE of Capella. The party headed NNW through open downs surrounding the spectacular tors of the southern Peak Range, which Leichhardt named after members of his party. This watershed was dry and the party, desperate for water turned north taking them back into low sandstone ranges running NNW. On their northerly course they came upon Hughes Creek, which they followed eastward to the vicinity of the Saraji Coal Mine, situated on extensive clay sheets that supported dense brigalow scrub. They travelled through the scrub along Hughes Creek until they reached its junction with the Isaacs River where they camped and reconnoitred for 6 days. The party headed up the Isaacs River generally in a northward direction. The country surrounding the narrow floodplain was predominantly eucalypt woodland interspersed with belts of brigalow. The party crossed the Peak Downs Highway on the 25 February passing by the mining town of Moranbah where basaltic soils support open eucalypt woodland and in places open grassland. Further north

---

[89] See also January 10

[90] On the second trip, Leichhardt observed 'Flindersia pyramidalis…., which I had seen at the Mackenzie' (Sprod 1989, p. 164)

[91] See also January 14

[92] See also January 16

the party passed by the Goonyella coal mine, before heading northeast up the Isaacs River towards the northern end of the parallel Kerlong and Carborough Ranges. The party camped at a narrow gorge that separates these north-south ranges from the Denham Range that runs northeast.

January 18

In a short time, we reached an open Bricklow [*Acacia harpophylla*][93] scrub containing many dry water-holes.

…continued our route through patches of Bricklow scrub, alternating with Bastard-box forest [*Eucalyptus cambageana* or *E. orgadophila*][94], and open Vitex [*Eremophila mitchellii*][95] scrub, in which the Moreton Bay ash [*Corymbia tessellaris*][96] was very plentiful. About eight miles from our camp, we came upon an open forest of narrow-leaved Ironbark (E. resinifera) [*Eucalyptus crebra*][97] and Bastard-box, covering gentle slopes…

... occasional ridges of open silver-leaved Ironbark [*Eucalyptus melanophloia*][98] forest. Among the latter was a rather stunted gum-tree, with a black scaly butt [probably *Corymbia dallachiana*]; it was very frequent, and greatly resembled the Moreton Bay ash.

…crossed a fine creek, with a reedy [possibly *Phragmites australis*][99] bed, along which lightly timbered flats extended…

We rode the whole day through a Bricklow thicket, which, in only three or four places, was interrupted by narrow strips of open country, along creeks on which fine flooded-gums [*Eucalyptus camaldulensis* or *E. tereticornis*][100] were growing.

In a recently deserted camp of the Aborigines, we found an eatable root, like the large tubers of Dahlia [*Cissus opaca*][101], which we greedily devoured…

We were then on a high box-tree [possibly *Eucalyptus populnea*] ridge, in view of a thick scrub….

A Grevillea (G. ceratophylla *R.Br.*?) with pinnatifid leaves, a small tree from fifteen to twenty feet high, and about four inches in diameter [*Grevillea parallela*][102]; a Melaleuca about the same size, with stiff lanceolate leaves, about two inches long and half an inch broad, and slightly foliaceous bark [*Melaleuca nervosa*][103]; and an Acacia with glaucous bipinnate leaves [possibly *Acacia storyi*], of the section of the brush Acacias of Moreton Bay—grew on the sandy soil along the ridges, and a handsome Convolvulus with pink flowers [possibly *Polymeria pusilla* or *Convolvulus graminetinus*] adorned the rich plain south-east of Mount Stewart.

Charley found many nests of the native bee, full of the sweetest and most aromatic honey we had ever tasted. The wild Marjoram [*Ocimum tenuiflorum*][104], which grows abundantly here, and imparts its fragrance even to the air, seemed to be the principal source from which the bee obtained its honey.

Extensive flats of rotten ground, but beautifully clothed with tufts of grass, openly timbered with Moreton Bay ash and flooded-gum, ascend into gentle grassy slopes of silver-leaved Ironbark and bloodwood [probably *Corymbia clarksoniana*][105], and then rise into sandstone ridges with Acacia [*Acacia shirleyi* or *A. catenulata*][106] thickets and shrubby plants peculiar to the sandstone formation. An Acacia with very large falcate, glaucous phyllodia [possibly *Acacia cretata*], and the Euphorbiaceous Severn-tree [*Petalostigma pubescens*], were very plentiful; and Crinum [*Crinum flaccidum*][107] grew in thousands on the sandy flats.

---

[93] See also January 18, February 3, 12, 29

[94] See also January 18, 26, February 3, 7, 8, 15, 22, 29, March 5

[95] See also February 12

[96] See also January 18, February 15

[97] See also January 18, 26, 30, February 2, 3, 6, 8, 15, 29, March 5, 7

[98] See also January 18, March 5

[99] See also January 18, 26, February 13, 15, 22, 24, 26, March 5

[100] See also January 18, 30, February 13, 15, 26

[101] See also February 13 where Leichhardt described the plant more fully 'The yams proved to be the tubers of a vine with blue berries; both tubers and berries had the same pungent taste, but the former contained a watery juice, which was most welcome to our parched mouths. A similar tuber was found near Mount Stewart on the 18th January'.

[102] See also February 12

[103] See also January 26

[104] See also January 18, March 7. Chisholm (1955) ascribed this to *Ocimum sanctum*, a synonym of *O. tenuiflorum*

[105] See also February 15

[106] See also February 3

[107] See also January 30

January 26

On the ridges, we observed Persoonia with long falcate leaves [*Persoonia falcata*]; the grass-tree (Xanthorrhaea) [*Xanthorrhoea johnsonii*][108]; the rusty gum [*Corymbia leichhardtii*][109], and the Melaleuca of Mount Stewart.

These pools were generally lined with patches of a narrow-leaved tea tree [probably *Melaleuca bracteata*]; and were full of basaltic pebbles.

January 27

The plains in the neighbourhood of our intended camp were richly grassed; and a species of Hypoxis [*Hypoxis arillacea*] and the native Borage (Trichodesma zeylanica, R. Br.) [*Trichodesma zeylanicum*] adorned them with their bright yellow and blue blossoms.

On the ridges which bounded the plain to the westward, I met with Acacia pendula [*Acacia pendula*]; and I may here remark that this appears to be the most northern limit of its habitat[110].

January 29

John Murphy brought the flower of a yellow Hibiscus from Roper's Peak [*Hibiscus divaricatus* or *H. heterophyllus*]: it is certainly a new species.

January 30

Nature looks quite refreshed; the grass is so green, and the modest blue Ruellia [*Brunoniella australis*] so plentiful...

January 31

... the creek went to the north-east, several other creeks joining it; that, lower down, it was lined with Casuarinas [*Casuarina cunninghamiana*][111]

February 2

In passing the foot of the peaks, we found a species of Grewia (Dwarf Roorajong) [*Grewia latifolia* or *G. retusifolia*] covered with ripe fruit; the fruit is dry, but the stringy tissue which covers the seed, contains a slightly sweet and acidulous substance of a very agreeable taste. The fig-tree with a rough leaf [*Ficus opposita*], had plenty of fruit, but not yet ripe. Erythrina [*Erythrina vespertilio*][112] was both in blossom and in seed.

I passed some gentle well-grassed slopes of narrow-leaved Ironbark and spotted gum [*Corymbia citriodora* subsp. *citriodora*]...

February 3

I observed on the ridges an Acacia, a small tree, from thirty to forty feet high, and from six to nine inches in diameter, and easily distinguished by its peculiar rough frizzled bark [*Acacia rhodoxylon*], similar to that of the Casuarina found at the ranges of the Robinson. It has a dark sweet-scented heartwood, like that of the Bricklow and the Myal and other Acacias, which I had previously met with.

February 5

Acacia farnesiana [*Acacia farnesiana*] grew in low shrubs along the plains, stretching its flexible branches over the ground; Mimosa terminalis (the sensitive plant) was very plentiful, and more erect than usual [possibly *Neptunia monosperma*]; a species of Verbena, with grey pubescent leaf and stem [*Verbena macrostachya*], was also abundant.

---

[108] See also February 12, 15

[109] See also February 6

[110] An accurate observation by Leichhardt

[111] See also January 13, 15, 24

[112] See also February 6

February 6

In a hollow between the two rocky protuberances on the west side of the hill, a noble fig-tree spread its rich dark-green shady foliage [*Ficus rubiginosa* or *F. virens*]…

February 7

On the sandstone range I found Balfouria saligna *R.Br.*, a shrub or small tree, with long, linear-lanceolate leaves, and rather drooping branches, covered with very fragrant yellow blossoms; its seed-vessels varied from three to six inches in length, were terete, tapering to a point, and filled with silky seeds [*Wrightia saligna*]. The same little tree was subsequently observed, growing round the head of the gulf of Carpentaria, and also at Arnheim's Land. Another shrub (Gardenia?), with opposite, oval, rather rough leaves, and white or light yellow blossoms [*Larsenaikia ochreata*], like those of the Jasmine in shape and fragrance, had been observed once before, but was very common between this latitude and Port Essington; at which place a species of Guettarda, resembling it very much, but with larger flowers, grows along the beach.

February 8

In one of the glens among the ridges I observed a new gum-tree, with a leaf like that of the trembling poplar of Europe, and of a bright green colour, which rendered the appearance of the country exceedingly cheerful [*Eucalyptus platyphylla*][113]. It is a middle-sized tree, of irregular growth, with white bark; but the wood, not being free grained, was unfit for splitting.

February 12 (pp. 143–146)

… on the upper part of Hughs's Creek, we first met with the drooping tea-tree (Melaleuca Leucodendron?) [*Melaleuca leucadendra* or *M. fluviatilis*], which we found afterwards at every creek and river; it was generally the companion of water, and its drooping foliage afforded an agreeable shade, and was also very ornamental.

Brown brought the fruit of a tree, which, according to his account, had the simple pinnate-leaf of the red cedar (Credela) with a dark purple-coloured fruit, half an inch long, and one inch in diameter, with a thin astringent pericarp: the stony seed-vessel consisted of many carpels, which, if I remember rightly, were monosperme [*Pleiogynium timorense*][114]. It belongs probably to an Ebenaceous tree. We again enjoyed some fine messes of Portulaca [*Portulaca oleracea*].

February 12 (p. 148)

In the scrub, Fusanus was observed in fruit [*Owenia acidula*], and the Stenochilus [*Eremophila maculata*] and the white Vitex in blossom; from the latter the native bee extracts a most delicious honey. A small tree, with stiff alternate leaves scarcely an inch long, was covered with red fruit of the form of an acorn, and about half an inch long, having a sweet pericarp with two compressed grain-like seeds, which had the horny albumen of the coffee, and were extremely bitter [*Diospyros humilis*].

February 15

The nature of the soil was easily distinguished by its vegetation: the Bastard box [*Eucalyptus coolabah*], and Poplar gum grew on a stiff clay…

... the forest oak (Casuarina torulosa) [probably *Allocasuarina littoralis*], together with rusty-gum [*Corymbia aureola, C. trachyphloia* or *C. leichhardtii*], were frequent on the sandy ridges.

Charley had, during my absence from the camp, had an interview with the natives, who made him several presents, among which were two fine calabashes which they had cleaned and used for carrying water; the larger one was pear–shaped, about a foot in length, and nine inches in diameter in the broadest part, and held about three pints [*Lagenaria siceraria*][115].

February 24

In the hollows along the Isaacs, we found a new species of grass from six to eight feet high, forming large tufts, in appearance like the oat-grass (Anthistiria) of the Liverpool Plains and Darling Downs; it has very long brown twisted beards, but is easily distinguished from Anthistiria by its simple ear [*Heteropogon triticeus*]; its young stem is very sweet, and much relished both by horses and cattle.

---

[113] See also February 8, 12, 15

[114] See also March 5

[115] This gourd may have been transported from another region.

February 26

I found a shrubby prickly Goodenia, about four or five feet high [*Scaevola spinescens*], growing on the borders of the scrub.

Undated (1–4 March)

A yellow [*Hibiscus divaricatus* or *H. heterophyllus*], and a pink Hibiscus [*Hibiscus* sp.] were frequent along the river.

March 5

… came through a narrow mountain gully, the passage of which was very much obstructed by tea-trees [probably *Melaleuca bracteata* or *M. trichostachya*].

The Corypha palm [*Livistona decora*][116] is frequent under the range.

Section 5. Suttor (March 8-April 1 1845)

Having traversed the Denham Range the party was now at the headwaters of Suttor Creek and had entered the catchment of the Burdekin River. The party headed west along Suttor Creek, at first encountering areas of dense brigalow scrub. In the vicinity of 'Suttor Creek' homestead the party left the stream travelling overland in a westerly direction through open plains and brigalow scrub, before coming to the upper reaches of the Suttor River upstream of its junction with Suttor Creek. The party followed the Suttor River downstream mostly through eucalypt woodland and brigalow scrub. Sandstone and acid volcanic rock supporting shrubby forest bordered the upper Suttor to the north-west contrasting with broad featureless flats on the lower reaches where the river separates into numerous anabranches. Downstream of the junction with the Belyando, the Suttor River flows north and the flood plain narrows. In this vicinity the party would have seen their last extensive brigalow scrub. The lower Suttor River becomes constrained by a landscape of low hills comprising metamorphosed sediments, granite and sandstone supporting eucalypt woodland. The Cape River and then the Sellheim River join the Suttor before its junction with the Burdekin River. The confluence of these streams is now under the water of the Burdekin Dam. Ten kilometres before reaching the Burdekin they diverted from the course of the Suttor River traversing to the east of Mount McConnell.

March 8

As we followed the creek about nine miles farther down, it became broader, and the Casuarinas [*Casuarina cunninghamiana*][117] were more frequent. Its bed was sandy, occasionally filled with reeds [*Phragmites australis*][118]…

March 10

The variety of grasses is very great; the most remarkable and succulent were two species of Anthistiria [*Themeda triandra* and *T. avenacea*], the grass of the Isaacs [*Heteropogon triticeus*], and a new one with articulate ears and rounded glumes [probably *Mnesithea rottboellioides*]. A pink Convolvulus, with showy blossoms [*Polymeria pusilla* or *Convolvulus graminetinus*], is very common. Portulaca, with terete leaves [*Portulaca filifolia* or *P. australis*], grows sparingly on the mild rich soil.

Were a superficial observer suddenly transported from one of the reedy ponds of Europe to this water-hole in Suttor Creek, he would not be able to detect the change of his locality, except by the presence of Casuarinas and the white trunks of the majestic flooded-gum [*Eucalyptus camaldulensis*][119]. Reeds, similar to those of Europe, and Polygonums [*Persicaria* spp.][120] almost identical as to species, surround the water, the surface of which is covered with the broad leaves of Villarsia [probably *Nymphoides indica*], exactly resembling those of Nymphaca alba, and with several species of Potomogeton [*Potamogeton* spp.].

There were occasional tracts of 'devil-devil' land, and patches of scrub, which, at no great distance, united into one mass of Bricklow [*Acacia harpophylla*][121].

---

[116] formerly *Livistona decipiens* (see Dowe and Jones 2004)

[117] See also March 10, 13, 15

[118] See also March 10, 12, 13, April 2

[119] See also March 13, 15, 17, 20, 25, 27

[120] See also March 20, 25

[121] See also March 12, 17

March 12

This scrub, like those already mentioned, varies in density and in its composition; the Bricklow acacia predominates; but, in more open parts, tufts of Bauhinia covered with white blossoms [*Bauhinia hookeri*], and patches of the bright green Fusanus [*Owenia acidula*] and silvery Bricklow, formed a very pleasing picture. The bed of the Suttor was rather shallow, sandy, and irregular, with occasional patches of reeds; its left bank was covered with scrub; but well grassed flats, with Bastard-box [*Eucalyptus coolabah*] and Ironbark [probably *Eucalyptus crebra*], were on its right.

March 13

… low ridges, covered either with scrub or with a very stunted silver-leaved Ironbark [*Eucalyptus shirleyi* or *E. melanophloia*][122]…

… A Melaleuca with very small decussate leaves, a tree about twenty-five feet high [*Melaleuca tamariscina*], was growing on the scrubby ridges.

A Ruellia, with large white and blue flowers [*Dipteracanthus australasicus* subsp. *australasicus*], adorned the grassy flats along the Suttor.

March 15

The scrub is generally an open Vitex [*Eremophila mitchellii*][123]; a fine drooping tea-tree [*Melaleuca fluviatilis* or *M. leucadendra*][124] lines the banks of the river…

The Mackenzie-bean [*Canavalia papuana*] and several other papilionaceous plants, with some new grasses, grow in it.

The most interesting plant, however, is a species of Datura [*Datura leichhardtii*], from one to two feet high, which genus has not previously been observed in Australia. I also found species of Heliotropium [*Heliotropium* sp.] of a most fragrant odour.

March 17

The Bricklow is here a real tree, but of stunted growth, with regularly fissured bark, like that of the Ironbark (Eucalyptus resinifera). It has long broad falcate phyllodia, whilst another species of the same size has an irregularly scaly bark, with small phyllodia, but of a grayer colour [*Acacia cambagei*] than those of the common Brickalow. Both species grow promiscuously together.

Where the river left the scrub, it entered into a wild water-worn box flat, and cut up into several irregular channels, lined by a dense thicket of narrow-leaved Melaleucas [*Melaleuca bracteata* or *M. trichostachya*] of stunted growth and irregular shapes. The Box-tree itself is here a different species, the bark has deeper fissures, and the young wood is very yellow [*Eucalyptus coolabah*][125]. I shall distinguish it by the name of 'Water-box,' as it grows exclusively near creeks, or on the neighbouring flats. I first observed it at the Mackenzie; its bark strips freely, but the stem is too short and irregular to be of any use.

… a long broad sheet of water stretched in sweeps through a dense Bauhinia [*Bauhinia carronii*] and Bricklow scrub, which covered its steep banks.

March 19

On the plains I found two new species of Sida; and, on the tea-trees, a new form of Loranthus, with flowers in threes on a broad leafy bract, scarcely distinguishable from the real leaves [*Diplatia furcata*].

March 20

The water-holes were surrounded by high Polygonums; blue Nymphaeas [probably *Nymphaea gigantea*][126] were observed in several of them …

---

[122] See also March 14, 27

[123] See also March 23

[124] See also March 19, 25, 27

[125] See also March 20, 23

[126] See also March 25

March 23

The melon-holes of the box-flats were frequently over-grown with the polygonaceous plant [*Muehlenbeckia florulenta*], mentioned at a former occasion; and the small scrub plains were covered with a grey chenopodiaceous plant from three to four feet high [probably *Salsola kali*]. The stiff-leaved Cymbidium [*Cymbidium canaliculatum*] was still very common, and two or three plants of it were frequently observed on the same tree; its stem is eatable, but glutinous and insipid.

On the banks of the more or less dry water-holes grows an annual leguminous plant, which shoots up into a simple stem, often to the height of twelve feet; its neck and root are covered with a spongy tissue; its leaves are pinnate, a foot or more in length, with small leaflets; it bears mottled yellow flowers, in axillary racemes [*Sesbania cannabina*][127]; and long rough, articulate pods, containing small, bright, olive-green seeds [*Aeschynomene indica*][128]. I first saw this plant at Limestone, near Moreton Bay, and afterwards at the water-holes of Comet River. It was extremely abundant in the bed of the Burdekin, and was last seen on the west side of the gulf of Carpentaria; I could, however, easily distinguish three species of this plant.

March 25

It was here we first met with Caryea arborea (Roxb.), a small tree from fifteen to twenty feet high, with elliptical leaves of soft texture, four inches long, and two in breadth; its fruit was about two inches long, contained many seeds, and resembled that of the Guava. Its leaves, however, had neither vernation nor the pellucid dots of Myrtaceous trees [*Planchonia careya*]. At the junction of the creek, a great number of small Corypha palms [*Livistona lanuginosa*] were growing, and my companions observed the dead stems of some very high ones, whose tops had been cut off by the natives, probably to obtain the young shoot.

… uniting into one deep channel, with long reaches of water surrounded by Polygonums, and overgrown with blue Nymphaeas, Damasoniums [*Caldesia oligococca*], and Utricularias [*Utricularia* spp.]…

March 27

The country back from the river is formed by flats alternating with undulations, and is lightly timbered with silver-leaved Ironbark, rusty gum [*Corymbia leichhardtii*], Moreton Bay ash [*Corymbia tessellaris*][129], and water box.

March 28

At some old camping places of the natives, we found the seed-vessels of Pandanus, a plant which I had never seen far from the sea coast; and also the empty shells of the seeds of a Cycas [*Cycas cupida* or *Livistona lanuginosa*][130]. Mr. Calvert, John Murphy, and Brown, whom I had sent to collect marjoram, told me, at their return, that they had seen whole groves of Pandanus trees; and brought home the seed-vessel of a new Proteaceous tree. I went to examine the locality, and found, on a sandy and rather rotten soil, the Pandanus abundant, growing from sixteen to twenty feet high, either with a simple stem and crown, or with a few branches at the top [*Pandanus* sp.]. The Proteaceous tree was small, from twelve to fifteen feet high, of stunted and irregular habit, with dark, fissured bark, and large medullary rays in its red wood: its leaves were of a silvery colour, about two inches and a half long, and three-quarters broad; its seed-vessels woody and orbicular, like the single seed-vessels of the Banksia conchifera; the seeds were surrounded by a broad transparent membrane [*Grevillea glauca*][131]. This tree, which I afterwards found everywhere in the neighbourhood of the gulf of Carpentaria, was in blossom from the middle of May to that of June. The poplar-gum, the bloodwood [probably *Corymbia clarksoniana*], the melaleuca of Mt. Stewart [*Melaleuca nervosa*], the Moreton Bay ash, the little Severn tree [*Petalostigma pubescens*], and a second species of the same genus with smooth leaves [*Petalostigma banksii*], were growing on the same soil. The grasses were very various, particularly in the hollows: and the fine bearded grass of the Isaacs grew from nine to twelve feet in height [*Heteropogon triticeus*]. Charley brought me a branch of a Cassia with a thyrse of showy yellow blossoms [*Cassia brewsteri*], which he said he had plucked from a shrub about fifteen feet high.

---

[127] Leichhardt seems to be including two species in a single description, as affirmed by a footnote: They belong probably to the two genera, Aeschynomene and Sesbania.

[128] *Sesbania cannabina* and *Aeschynomene indica* have similar habitats.

[129] See also March 28

[130] *Cycas cupida* is a rare species known to occur within 50 km of this location but is not known to occur near rivers. Leichhardt may have misidentified the large endocarps of the palm *Livistona lanuginosa,* although these are not known to be edible.

[131] a supplementary description is provided in a letter from Leichhardt to William Macarthur on the 18 July 1846: 'a small rather stunted tree with the dark fissured bark of the Ironbark tree: it has long lanceolate rather blunt leaves, with a silvery down at their lower surface. Its seed vessels resembled those of Banksia serrata (two round woody shells) or conchifera, its blossoms were white and formed long racemes. (Aurousseau 1968, p. 884)

Section 6. Burdekin (April 2-May 21 1845)

The party headed in a northerly direction up the Burdekin River that maintains a permanent stream for almost its entire length. Before the course of the river turns to the northwest, the stream cuts through dissected rocky granodiorite hills that made travelling difficult. After the turn in the river, a long stretch continues through granodiorite hills, but with a broader floodplain. On April 10, the party crossed the Flinders Highway to the east of Charters Towers and about 20km to the NW entered some rugged basalt areas, including the tail end of the geologically recent Toomba flows where Dalrymple National Park is situated. In places the party either left the river or travelled in its bed because of the difficulties of finding a course through this rugged rocky landscape. In general these rugged landscapes away from the river supported eucalypt woodland, although the areas of bare rock support dry rainforest. To the north of the Toomba flow, the basalt is older and more weathered, which allowed for easier travel to the junction of the Burdekin and Basalt Rivers. The party continued to follow the Burdekin in a northerly direction past its junction with the Star River, Running River, Clarke River and Christmas Creek through a hilly landscape dominated by metamorphosed sediments with occasional Tertiary sandstones. The area includes many stony ridges and gullies that often forced the party away from the stream itself to higher ground. Travel was particularly difficult in the area known as Hell's Gate where the Burdekin swings in a westerly direction through a rhyolite gorge. On April 30 they passed by Greenvale where the river flat of the Burdekin is mostly broad with open timbered flats. Upstream of the Dry River the Burdekin effectively runs along the divide between basalt to the west and metamorphosed sediments and occasional acid volcanics to the east. The eucalypt woodlands are more open and grassy on the basalt and the party generally followed up the western side of the stream, although the rockiness of this terrain made travel with the horses difficult. Near the junction of Reedy Brook and the Burdekin River, large lagoons prompted Leichhardt to name this area the 'Valley of Lagoons'. To the north of these lagoons is a basalt lava field (the tail of the geologically recent Kinrara basalt flow) that caused Leichhardt to spend two days determining a route that avoided the fresh basalt lava (supporting dry rainforest) and rock fields (supporting open eucalypt woodland). In places, ridges descending from the northern end of Pelican Lake Range interspersed the flat basalt and alluvium. On the 16 May they left the Burdekin and headed north up Anthill Creek which continued the separation of the basalt plains to the west and the hills of metamorphics and granites to the east. While the party camped near the head of Anthill Creek in the vicinity of 'Glen Harding' homestead, Leichhardt searched for a route that would provide water. They then headed overland for a long days travel in a NNW direction, through granitic and basaltic geologies, passing by G.W. swamp, Native Wells swamp, then through a long stretch of open woodland on basaltic terrain, before arriving at the head of Rudd Creek (the Separation Creek of Leichhardt) in the catchment of the Herbert River. After a two-day rest they headed west through more heavily timbered granitic country crossing the Great Dividing Range and the Kennedy Highway.

April 2

Mr. Gilbert found a large calabash attached to its dry vine [*Lagenaria siceraria* or *Benincasa hispida*], which had been carried down by the waters.

April 3

Among the patches of brush which are particularly found at the junction of the larger creeks with the river, we observed a large fig-tree, from fifty to sixty feet high, with a rich shady foliage; and covered with bunches of fruit [*Ficus racemosa*][132]. The figs were of the size of a small apple, of an agreeable flavour when ripe, but were full of small flies and ants. These trees were numerous, and their situation was readily detected by the paths of the natives leading to them: a proof that the fruit forms one of their favourite articles of food. The drooping tea trees [*Melaleuca fluviatilis* or *M. leucadendra*][133], which had increased both in number and size, grew in company with an arborescent Calistemon [*Callistemon viminalis*][134], along the water's edge; and a species of Eucalyptus, somewhat resembling Angophora intermedia [possibly *Corymbia setosa*], was discovered at this spot: it occurs frequently to the northward, and is common round the gulf of Carpentaria. The small Acacia tree of Expedition Range [*Acacia bidwillii*][135] was frequently seen in the forest, and was covered with an amber-coloured gum, that was eatable, but tasteless: Hakea lorea (R. Br.) [*Hakea lorea*][136], and Grevillea ceratophylla (R. Br.) [*Grevillea parallela*]; the Ebenaceous tree [*Pleiogynium timorense*][137], and that with guava-like fruit (lareya) [*Planchonia careya*], were all numerous. The bed of the river was covered with the leguminous annual [*Sesbania cannabina*] I noticed at the Suttor; it grew here so high and thick that my companions were unable to see me, though riding only a few yards from them.

---

[132] See also April 5, 7, 8, 12, 14

[133] See also April 9, 23, May 1, 6, 11, 21

[134] See also May 9

[135] See also April 9

[136] See also April 21, May 1

[137] See the more detailed description of February 12

April 4

… open narrow-leaved Ironbark forest [*Eucalyptus crebra* or *E. xanthoclada*][138] on a granitic sand…

April 5

We observed the poplar-gum again in the open forest, and a fine drooping loranthus [*Amyema miquelii*] growing on it. Pandanus [*Pandanus* sp.][139] was also very frequent, in clusters from three to eight trees.

… the top of the hill, which is wooded with a silver-leaved Ironbark [*Eucalyptus shirleyi* or *E. melanophloia*][140], …

April 6

… several sandy creeks, in which a species of Melaleuca [*Melaleuca* sp.], and another of Tristania [*Lophostemon grandiflorus*] were growing…

April 8

Besides the clustered fig, and another species with rough leaves and small downy purple fruit [*Ficus opposita*] there were a species of Celtis [*Celtis paniculata*]; the Melia azederach (White Cedar) [*Melia azedarach*]; a species of Phyllanthus (a shrub from six to ten feet high) [*Breynia oblongifolia, Flueggea leucopyrus* or *Bridelia leichhardtii*][141]; an Asclepiadaceous climber, with long terete twin capsules [possibly *Gymnanthera oblonga* or *Secamone elliptica*]; and several Cucurbitaceae, one with oblong fruit about an inch long, another with a round fruit half an inch in diameter [probably *Cucumis melo*], red and white, resembling a gooseberry [*Diplocyclos palmatus*]; a third was of an oblong form, two inches and a half long and one broad [probably *Momocordia charantia*] ; and a fourth was of the size and form of an orange, and of a beautiful scarlet colour [*Trichosanthes pentaphylla*][142]: the two last had an excessively bitter taste. …

April 9

The country was openly timbered; the Moreton Bay ash [*Corymbia tessellaris*][143] grew along the bergue of the river, where a species of Grewia [probably *Grewia retusifolia*][144] seemed its inseparable companion. The flooded-gum [*Eucalyptus camaldulensis*][145] occupied the hollows and slopes of the river banks, which were covered with a high stiff grass [possibly *Arundinella nepalensis*][146] to the water's edge, and the stream was fringed with a thicket of drooping tea trees, which were comparatively small, and much bent by the force of floods, the probable frequency of which may account for the reduced size of the tree. The ridges were covered with rusty Gum [*Corymbia leichhardtii*] and narrow-leaved Ironbark. An Erythrina [*Erythrina vespertilio*][147] and the Acacia of Expedition Range were plentiful.

April 10

A shrubby Clerodendron [*Clerodendrum floribundum*] and an arborescent Bursaria, covered with white blossoms [*Bursaria incana*] adorned the forest.

---

[138] See also April 7, 9, 12, 14, 16, 18, 19, May 5, 10, 11

[139] See also April 13, May 16 and 17

[140] See also April 9, 19, 22

[141] No *Phyllanthus* sp. achieves this size. On Leichhardt's second expedition he refers to a 'phyllanthus with red fruit' in the Dawson area (30 Jan., Sprod 1989, p. 159). This can certainly be ascribed to *Breynia oblongifolia*

[142] All specimens of *Trichosanthes pentaphylla* at the Queensland Herbarium are from higher rainfall environments, although Mueller collected it from the 'Burdekin River' (Telford 1982). Leichhardt described the flowers on April 13. See also April 19

[143] See also April 12, 23, May 2, 10

[144] See also May 20

[145] See also May 2, 3, 11, 21

[146] See also April 13, May 1

[147] See also April 14

April 11

Farther on, however, we occasionally met with patches of Vitex scrub [*Eremophila mitchellii*][148], and crossed some stony ridges.

On the rocky crest of the hill, I gathered the pretty red and black seeds of a leguminous climbing shrub (Abrus precatorius) [*Abrus precatorius*].

April 12

Box-tree [probably *Eucalyptus brownii*][149] flats and open Vitex scrub extended along its banks, and the latter according to Mr Roper's account changed into dense Bricklow [*Acacia harpophylla*] scrub.

The basalt ceased to the westward of the limestone hill, and was succeeded by considerable flats of Ironbark, Moreton Bay ash, and Bloodwood [*Corymbia clarksoniana* or *C. erythrophloia*]. The Capparis [possibly *Capparis canescens*] still exhibited a few showy flowers.

April 13

Some days ago I found, for the first time, Spathodea alternifolia (R. Br.) [*Dolichandrone alternifolia* or *D. heterophylla*], which we continued to meet with throughout the remainder of our journey. I saw but one flower of it, but its falcate seed-vessels, often more than a foot long, were very numerous.

A Bottle-tree with a Platanus leaf (Sterculia?) [*Brachychiton australis*][150] grew in the scrub on the field of basalt, and was in full blossom. A pretty species of Commelyna [*Commelina ensifolia* or *C. lanceolata*], on the flats, a cucurbitaceous plant with quinquepalmate leaves and large white blossoms, grew along the river, the approaches of which were rendered almost inaccessible by a stiff high grass. Charley brought me the long flower-stalk of Xanthorrhaea [*Xanthorrhoea johnsonii*] from some ridges, which were, doubtless, composed of sandstone.

April 16

In the thicket which covered the rock, I observed Pomaderris of Moreton Bay [*Alphitonia excelsa*].

April 18

Among the shrubs and grasses, a downy Abutelon [*Abutilon calliphyllum, A. leucopetalum* or *A. nobile*] was easily distinguished by its large bright yellow blossoms.

April 19

Mr. Phillips found a flesh-coloured drupaceous oblong fruit, about half an inch long, with a very glutinous pericarp, containing a slightly compressed rough stone [*Cordia dichotoma*]: in taste it resembled the fruit of Loranthus, and the birds, particularly the cockatoos, appeared very fond of it. We all ate a great quantity of them, without the slightest injury. It grew on a small tree, and had a persistent calyx.

April 20

I had the pleasure of finding some very interesting plants on its summit; particularly a small Acacia with verticillate leaves [*Acacia galioides*], which Dr. Binoe, the surgeon of H. M. S. Beagle, had found on the north-west coast; and two other Acacias equally new to me [*Acacia* spp.], and which were afterwards found to extend to the heads of the South Alligator River.

---

[148] See also April 12, 14, 16, 23

[149] On April 13, Leichhardt noted 'The box (Eucalyptus), on the flats along the creek, the soil of which is probably formed of the detritus of basaltic rock, had a lanceolate glossy leaf, uniting the character of the box with glossy orbicular leaves growing generally on the whinstone soil of the northern parts of the colony, and of the box with long lanceolate leaves which prefers stiff flats on the tributary creeks of the Hunter.' This description clearly pertains to *Eucalyptus brownii* as probably do other references to 'box' in this section. See also April 13, 14, 16, 25, May 1, 2, 5, 11

[150] See also May 3, May 6

April 21

…on the rocky slopes I found a new species of Hakea, having linear lanceolate leaves with axillary fascicules of small brownish flowers [*Hakea arborescens*][151]: it was an arborescent shrub, from three to six feet high; and is nearly allied to H. arborescens (*R. Br. Prodr.* p. 386).

April 22

I have mentioned a small round eatable tuber, which I found in the basket of a native gin on the 2nd January. I here found it to be the large end of the tap root of a Potamogeton [probably *Triglochin* sp.], or a plant nearly allied to that genus; I found it with another interesting water-plant, with foliated spikes of blue flowers [*Monochoria cyanea*], in a small water-hole near our last camp.

April 23

These flats were separated by shallow gullies, and some Casuarina [*Casuarina cunninghamiana*][152] creeks …

April 30

Several familiar forms of plants were discovered; also a new Eucalyptus, with a glaucous suborbicular subcordate leaf, and the bark of the rusty gum [*Corymbia peltata*]: a stunted or middle-sized tree, which grew in great abundance on the ranges …

A large tree, with dark green broad lanceolate stinging leaves [*Dendrocnide photinophylla*], grew on its banks; it resembled the nettle tree, but belonged to neither of the two species growing in the bushes of the east coast.

May 1

A species of Acacia with narrow blunt phyllodia, about an inch long, with spinous stipules [*Acacia victoriae*]; Hakea lorea, and the Grevillea mimosoides (R. Br.), with very long linear leaves [*Grevillea striata*], were frequent.

May 2

…the dry channel of a river, with reeds [*Phragmites australis*][153] and occasional water-holes…

May 3

After turning round the field of lava to the eastward, we entered into a large flat, with patches of narrow-leaved tea tree [*Melaleuca bracteata*][154], with reedy swamps and fine flooded-gum trees, and made our camp at a strong running brook, without trees, but densely surrounded with reeds, ferns, and pothos[155].

At the foot of the eastern hills, however, deep holes existed in a water-course, with black blocks of basalt heaped over each other, on which the fig tree [probably *Ficus virens*][156] with its dark green foliage formed a shady bower, most delightful during the heat of the day.

A native low shrubby Mulberry [*Pipturus argenteus*][157] was found in this scrub, the fruit of which was good to eat, but of very small size.

From the top of the hills I enjoyed a most beautiful view of the valley of the river, with its large lagoons covered with Nymphaeas [*Nymphaea gigantea* or *N. violacea*][158] and Damasoniums [*Caldesia oligococca*].

---

[151] See also May 21

[152] See also April 23, 30, May 1, 2, 9, 10, 11, 21

[153] See also May 3, 4, 5, 6, 11, 21

[154] See also May 5, 20

[155] In Gilbert's unpublished journal he states 'Here we first saw the genus of Plothos a species of Nymphaea'. This may be a misunderstanding on Gilbert's part. The identity of pothos (spelt as plothos on May 6) is uncertain.

[156] See also May 11

[157] See also May 11

[158] See also May 6, 11, 15

May 4

During one of the last stages, we discovered a leguminous tree, with the dark fissured bark of the Ironbark, but with large bipinnate leaves, the leaflets oblong, an inch in length; the pods broad and thin, and two or three inches long [*Erythrophleum chlorostachys*]: this tree is common all over the northern part of the continent, and was found growing abundantly around Victoria, the principal settlement of Port Essington.

May 5

I followed the base of the basaltic table land, along which the brook came down, and, after a two miles' ride on its banks, through oak trees [*Casuarina cunninghamiana*][159], low fern trees [possibly *Cycas desolata*][160], and several bush trees, found that it came down a valley deeply cut into the table land.

May 10

Tristania [probably *Lophostemon suaveolens*], with pubescent leaves round some lagoons…

May 11

Oak trees and drooping Melaleucas [*Melaleuca fluviatilis or M. leucadendra*] grew abundantly in its bed, and along the banks.

I have to mention that a species of Sciadophyllum, nearly allied to Sc. lucidum, (*Don.* iii. p. 390,) was found in the lava scrub of the valley of lagoons: it was a small tree with digitate leaves, composed of from eleven to thirteen oblong acuminate, glabrous leaflets, which were about five inches long; and it attracted the attention of my companions as much by its ornamental foliage at its numerous terminal racemes of bright scarlet flowers [*Schefflera actinophylla*].

The upper parts of the small creeks, which come down in these plains, were full of water, and had their source generally between heaps of bare basaltic rocks, surrounded by rich grass, and a scanty scrub of Pittosporum [possibly *Denhamia pittosporoides*], of the native mulberry, of the fig-tree, and of several vines, with Polypodiums, Osmundas [probably *Cyclosorus interruptus*], and Caladiums [*Alocasia brisbanensis*][161] growing between them.

…a great number of rocky basins within the basalt, and surrounded by its black blocks, formed evidently so many lagoons during the wet season, as sedges and Polygonums [*Persicaria* sp.]—always inhabitants of constantly moist places—grew abundantly in most of them

May 16 and 17

Pandanus spiralis fringed the scattered water-holes; and Grevillea chrysodendron, (*R. Br.*) [*Grevillea pteridifolia*][162] formed a wreath, of pale silver-colour, round the swamps, but grew on sandy soil.

May 20

The stringy bark tree [*Eucalyptus tetrodonta*], and Tristania [*Lophostemon grandiflorus* or *L. suaveolens*] were growing on the sandy soil, and the latter near watercourses.

---

[159] See also May 11, 16 and 17

[160] It seems possible that Leichhardt is referring here to a cycad. His observation of these 'low fern trees' was made while reconnoitering with Charley. Cycads were seen by the party on May 3, as testified by Gilbert in his diary entry for May 3: *'the Basalt, on a flat, was a fine species of Zamia, having glaucous leaves, some of them having stems from four to six feet in height, it was confined to an area not more than half a mile around, it is certainly a very elegant plant, the seed of which proves to be one of the articles of food among the Natives.'* This is undoubtedly *Cycas desolata* P.I. Forst., a species rediscovered in 1992 and formally described in 1995. Leichhardt did not note this species in his published journal but did note its presence in retrospect, when comparing it with the cycads at Port Essington. 'The Cycas appears to be of different species from that at least of the Burdekin' (Webster 1986, p. 33). It is also conceivable that this could be a tree fern. If this were the case the most obvious candidate would be *Cyathea cooperi*, which has been collected in a more mesic environment about 40 km distant from this location.

[161] See Leichhardt's letters (Aurousseau 1968, Vol. 2, p. 683) for full description.

[162] See also May 20

May 21

Large blocks of granite crested the summits of the hills, and their slopes were covered with Acacia thickets [*Acacia shirleyi*], and arborescent Hakeas and Grevilleas. A dwarf Acacia, with rhomboid downy phyllodia, an inch long [probably *Acacia humifusa*], grew between the rocks.

Section 7. Lynd-Mitchell (May 22-June 25 1845)

The party entered the watershed of the Gulf of Carpentaria near the headwater of Nobbs Creek that they followed for a short distance to the Lynd River. They followed down the valley of the Lynd that dissects low ranges of metamorphics, rhyolite and sandstone supporting eucalypt woodlands. In places, the rugged topography kept the party a little back from the river itself. The stream breaks out from the ranges onto the flat plains of the Gulf of Carpentaria hinterland about 20 km south of the 'Bulimba' homestead. The landscape of the lower Lynd is typical of the region and is comprised of a matrix of Melaleuca and Eucalyptus dominated woodlands with occasional treeless plains. The party continued to follow the Lynd River until near its junction with the Mitchell River, which they bypassed on the 15 June. The party travelled down the Mitchell River but well back from the southern bank to avoid gullies, passing by a number of lagoons associated with the floodplain. They followed the river to a point about 25km WNW of 'Koolatah' where Leichhardt decided that they had proceeded too far to the north and should head west to the coast where they could follow the coast of the Gulf of Carpentaria in their desired direction.

May 22

At the westerly creek I found a rose-coloured Sterculia, with large campanulate blossoms and tomentose seed-vessels [*Brachychiton albidus* or *B. chillagoensis*][163]: the tree had lost all its foliage. I had met with this species on the rocky ranges of Moreton Bay (at Mount Brisbane), but there it was a low shrub, whereas in this place, and all round the gulf of Carpentaria, it formed a middle sized tree with spreading branches. A new Hakea, with long thin terete leaves (different from H. lorea) [*Hakea persiehana*] and Grevillea chrysodendron [*Grevillea pteridifolia*], grew along the creek. Grevillea ceratophylla (R. Br.) [*Grevillea parallela*] and another Grevillea, with a compound terminal thyrsus, and long lanceolate falcate leaves [*Grevillea mimosoides*], grew on the slopes, in company with a Xylomelum [*Xylomelum scottianum*]. with smooth and smaller seed-vessels than those of X. pyriforme. The rocky ridges were occupied by the stringy-bark [*Eucalyptus tetrodonta*][164], fine Cypress-pine trees [*Callitris intratropica*], the stunted silver-leaved Ironbark [*Eucalyptus shirleyi*][165], a Eucalyptus, with very scanty foliage, orange-coloured blossoms, seed-vessels longitudinally ribbed, and as large as the egg of a fowl; its butt was covered with a lamellar bark, but the upper part and the branches were white and smooth [*Eucalyptus chartaboma*]; also by another Eucalyptus, with a scaly butt like the Moreton Bay ash, but with smooth upper trunk and cordate ovate leaves [*Corymbia confertiflora*][166], which was also new to me; we called it the Apple-gum. We frequently met with the grass tree (Xanthorrhaea.) [*Xanthorrhoea johnsonii*].

May 26

The ranges formed the banks of the river itself, and even entered its bed, which gradually enlarged and was frequently formed by several channels fringed with large drooping tea trees [*Melaleuca leucadendra, M. fluviatilis* or *M. argentea*][167].

May 27

As soon, however, as the river had fairly left the basaltic formation, fine large flats of a light sandy soil succeeded on both sides; on which Pandanus spiralis [*Pandanus* sp.][168] grew in great abundance, and to a larger size than we had seen before.

Among the new and interesting scrubs and trees which we met with at almost every step, I shall only mention a small Grevillea, from one to two feet in height, with pubescent pinnatifid leaves, and a simple or compound thyrsus of scarlet flowers [*Grevillea dryandri*]; Cochlospermum gossypium, the native cotton tree of Port Essington, whose bright showy yellow blossoms and large capsules full of silky cotton, attracted our attention; its leaves are deciduous, and the trees were entirely leafless [*Cochlospermum gregorii*][169]; a fine species of Calytrix on the rocks [*Calytrix leptophylla*], and two of Loranthus on the drooping tea tree, the drooping foliage of which one of them imitated, whilst the other belonged to the group I mentioned as found at the Suttor, with its flowers inserted on a leafy bract [*Diplatia grandibractea*].

---

[163] See also May 27; the species he mentions seeing at Mt Brisbane is *Brachychiton bidwillii*

[164] See also May 27, June 3, 6, 8, 9, 13, 14, 16, 20

[165] See also June 3

[166] See also June 6, 11, 13, 20

[167] See also May 27, June 8, 9, 23, 25

[168] See also May 31

Exocarpus latifolius [*Exocarpos latifolius*][170] is so different from E. cupressiformis, in its foliage and aspect, that I did not suspect their near relation, until I found blossom and fruit: the ripe kernel as well as its yellow succulent leaf-stalk have a very agreeable taste; a leguminous shrub, about five or six feet high, with purple blossoms gathered into terminal oblong heads [*Cullen badocanum* or *Psoralea spicigera*]; this would be an ornament to our gardens. Along the river we discovered a large tree, about forty or fifty feet in height, with rather singularly disposed horizontal branches and rich dark green foliage; its leaves were oblong acute, and frequently a foot long; its flowers formed dense heads, which grew into a fleshy body marked with the areoles of every flower. It is either Sarcocephalus or Zuccarinia, or nearly allied to them [*Nauclea orientalis*][171]. The tree has never been seen on easterly waters, but it was the invariable companion of all the larger freshwater rivers round the gulf. A fine species of Gomphrena [probably *Gomphrena flaccida*] was found in the sandy bed of the river. A species of Terminalia, a fine shady tree, with spreading branches and broad elliptical leaves [*Terminalia platyphylla*], grew along the sandy creeks; and another smaller one with Samara fruit [*Terminalia platyptera*] preferred the rocky slopes. Both of these, and a third species growing on the west side of the gulph, which I shall have to mention hereafter, supplied us with fine eatable gum, and a fourth species, with smooth leaves, had an eatable fruit of a purple colour [probably *Terminalia subacroptera*].

Heaps of rocks with clusters of trees, particularly the smooth-leaved fig tree [*Ficus rubiginosa*], the rose-coloured Sterculia, Exocarpus latifolius, were scattered over the slopes, or grew on the summits…

…bustards were numerous on the small flats between basaltic hillocks, where they fed on the ripe fruit of Grewia [probably *Grewia retusifolia*][172].

May 31

Proceeding, we travelled over a broken and very stony country, with a stiff soil, but mixed with so much sand that even the Severn tree [*Petalostigma pubescens*][173] grew well. There was another small tree, the branches of which were thickly covered with bright green leaves; it had round inferior fruit, about half an inch in diameter, which was full of seeds [*Gardenia vilhelmii*][174]: when ripe, it was slightly pulpy and acidulous, and reminded me of the taste of the coarse German rye bread. In consequence of this resemblance, we called this little tree the Bread tree of the Lynd. I ate handfulls of this fruit without the slightest inconvenience. A species of Pittosporum [possibly *Denhamia pittosporoides*], and several Acacias, Pandanus, and the leguminous Ironbark [*Erythrophleum chlorostachys*], were scattered through an open forest of Ironbark [probably *Eucalyptus cullenii*][175] and lanceolate box [*Eucalyptus leptophleba* or *E. microneura*][176]. I observed here a very ornamental little tree, with drooping branches and linear lanceolate drooping leaves three inches long; it very much resembled a species of Capparis that I had seen at the Isaacs. Its blossoms are very small, and the calyx and corolla have each five divisions; the stamens are opposite the petals; it bore a fruit like a small apple, with a hard outside, but pulpy and many seeded within, like Capparis; the calyx was attached to the base of the fruit [*Siphonodon pendulus*].

The highest flood-marks we observed were from six to eight feet above the level of the bed; these marks were on the trunks of Casuarinas [*Casuarina cunninghamiana*], Melaleucas, and flooded-gum [*Eucalyptus camaldulensis*][177], which grew along the channel. The country in general had a winterly appearance; and the grass round the camp was dry, but I observed the fine grass of the Isaacs [*Heteropogon triticeus*][178]…

June 2

The river divided several times into anabranches, flowing round, and insulating rocky hills and ridges. It was much better supplied with water, and contained several large reedy [*Phragmites vallatoria*] lagoons. An elegant Acacia, about thirty or thirty-five feet high, grew on its small flats: it had large drooping glaucous bipinnate leaves, long broad pods, and oval seeds, half black, and half bright red [*Adenanthera abrosperma*].

---

[169] See also June 5, 20
[170] See also May 27
[171] See also June 5, 9, 23
[172] See also June 19
[173] See also June 13
[174] See also June 13
[175] Jackes (1990) ascribed this to *Eucalyptus crebra*. See also May 31, June 5, 6, 8, 14
[176] See also June 3, 5, 6, 9, 11, 13, 14, 16, 20, 25
[177] See also June 13, 20
[178] See also June 9

June 3

In their dillies I found the fleshy roots of a bean, which grows in a sandy soil, and has solitary yellow blossoms [probably *Eriosema chinense*]; the tuber of a vine, which has palmate leaves [*Cissus opaca*]; a bitter potato, probably belonging to a water-plant [possibly *Tacca leontopetaloides* or *Triglochin* sp.]…

June 5

The clustered fig tree [*Ficus racemosa*][179] of the Burdekin became again more frequent; but Sarcocephalus was the characteristic tree of the river. The Acacia of Expedition Range [*Acacia bidwillii*][180] and of the upper Lynd, grew to a comparatively large size in the open forest.

The bean of the Mackenzie [*Canavalia papuana*] was very abundant in the sandy bed of the river; we roasted and ate some of its fruit; it was, however, too heavy, and produced indigestion: Mr. Phillips pounded them, and they made an excellent substitute for coffee, which I preferred to our tea, which, at that time, was not very remarkable for its strength.

June 6

On the small flats, the apple-gum grew with a few scattered Moreton Bay ash trees; on the bergues of the river we found the white cedar (Melia azedarach)[*Melia azedarach*], Clerodendron [*Clerodendrum floribundum* or *C. tomentosum*]; an asclepiadaceous shrub with large triangular seed-vessels [probably *Tylophora erecta*]; and, on the hills, the blood-wood [*Corymbia* sp.][181] and stringy-bark.

June 8

A new species of Melaleuca [probably *Melaleuca stenostachya*] and also of Boronia [*Boronia bowmanii*] were found, when entering upon the sandstone formation.

June 9

The stringy-bark became even numerous on the flats, in consequence of the more sandy nature of the soil: but the hills were scrubby, and Mr. Gilbert reported that he had even seen the Bricklow [possibly *Acacia julifera* subsp. *gilbertensis*]. The grass of the Isaacs grew from twelve to fifteen feet high, in the hollows near the river, which was, as usual, fringed with Sarcocephalus; a species of Terminalia [*Terminalia* sp.]; the drooping tea-tree; and with an Acacia [probably *Acacia platycarpa*][182] which perfumed the air with the fragrant odours of its flowers.

June 13

A species of Stravadium attracted our attention by its loose racemes of crimson coloured flowers, and of large three or four ribbed monospermous fruit; it was a small tree, with bright green foliage [*Barringtonia acutangula*][183], and was the almost constant companion of the permanent water-holes. As its foliage and the manner of its growth resemble the mangrove, we called it the Mangrove Myrtle.

June 16

…we came to several very fine lagoons; one of which was several miles long, and apparently parallel to the river: it was exceedingly deep, and covered with the broad leaves of Villarsia [*Nymphoides indica* or *N. crenata*][184] and Nymphaea [*Nymphaea gigantea* or *N. violacea*][185]…

---

[179] See also June 23

[180] Jackes (1990) tentatively ascribed this to *Acacia holosericea*. See also June 13, 14, 15, 16

[181] See also June 13, 16, 20

[182] See also June 11

[183] See also June 23, 24

[184] See also June 19

[185] See also June 19, 24

In crossing one of the creeks we found a species of Acacia (Inga moniliformis, D. C. Prod. Vol. II. p. 440, where it is described as having been found at Timor.), with articulate pods and large brown seeds; it was a small tree with spreading branches, and a dark green shady foliage [*Cathormion umbellatum*][186]: it occurred afterwards on all the creeks and water-holes until we reached our destination.

June 19

The country along the Mitchell was an immense uninterrupted flat with a very clayey soil, on which the following plants were frequent: viz. Grevillea, Cerotaphylla [*Grevillea parallela*], and Mimosoides [*Grevillea striata*], a Melaleuca with broad lanceolate leaves [*Melaleuca viridiflora*], Spathodea [*Dolichandrone alternifolia* or *D. heterophylla*][187] and a Balfouria, *R. Br.* [probably *Wrightia saligna*][188].

June 20

Plains covered with high dry grass alternated with an open forest; in which we observed Spathodea, Bauhinia [*Bauhinia cunninghamii*][189], a Balfouria, groves of Cochlospermum gossypium, and several other trees, which I had seen in the scrubs of Comet River; among which was the arborescent Cassia with long pods [possibly *Cassia brewsteri*][190].

A pretty yellow Ipomoea [*Merremia hederacea*][191] formed dense festoons between the trees that fringed the waters.

June 21

…past several fine lagoons, richly adorned by the large showy flowers of a white Nymphaea [possibly *Nymphaea violacea*], the seed-vessels of which some families of natives were busily gathering…

… John Murphy and Brown brought the leaves of the first palm trees we had seen on the waters of the gulf. They belonged to the genus Corypha [*Corypha utan*][192]; some of them were very thick and high.

June 25

… we entered into a flat covered with stunted box, and intersected by numerous irregular water-courses. The box was succeeded by a Phyllanthus [probably *Flueggea virosa*] scrub, through which we pushed…

Section 8. Eastern Gulf of Carpentaria (June 26-August 20 1845)

The party traversed open plains passing several large lagoons associated with drainage lines some of which are named, including Diamond Creek and Tea Tree Creek, an upper tributary of the Nassau River. It was in the vicinity of the latter location that aborigines attacked the party on the night of June 28. Gilbert was killed and other party members were seriously wounded. After a few days recuperation the party continued in a south-westerly direction crossing Station, Cattle, Surprise and Salt Arm Creeks. Their travel must have been hampered by the serious injuries of Roper and Calvert, but their spirits were lifted by the presence of mangroves and other tidal communities that indicated the proximity of the coastline (about 20 km to the west). The party followed a broad arc taking them in a more southerly direction before they arrived at the Staaten River about 3km south-west of Galbraith homestead on July 7. They crossed the Staaten River at low tide before crossing Van Rook Creek, Bull Creek and Middle Creek before reaching the Gilbert River (Leichhardt's Van Diemen River) about 25km NW of the 'Stirling' homestead. The party continued in a southerly direction across the Smithbourne River (Leichhardt's Gilbert River), and then gradually to the south-west where they crossed the numerous channels including McLellans Creek before reaching Walker Creek (Leichhardt's Carron River), near where they camped for two nights to allow the debilitated Roper to recuperate. They continued in SSW direction crossing the Norman River on July 20 just north of the Gulf Development Road about 20km south of Normanton. They proceeded in a generally westerly direction crossing the Bynoe River (Leichhardt's Big Plain Creek) and Flinders River just north of their separation. They then headed south up Armstrong Creek to avoid

---

[186] Jackes (1990) tentatively ascribed this to *Acacia bidwillii.*

[187] See also June 20

[188] See also June 20

[189] Later in this paragraph Leichhardt gives a fuller description, 'A Bauhinia, different from the two species I had previously seen, was covered with red blossoms, which, where the tree abounded, gave quite a purple hue to the country'.

[190] This record is a long way distant from the currently known distribution of *C. brewsteri*

[191] Compare this reference to July 12

[192] See also June 23, 24, 25

this salty waterless country before heading west again to L Creek, upstream from Inverleigh homestead. In this area they witnessed the vast treeless grasslands of the Gulf Plains. They then curved back to the northward through more wooded country and over Pongdestre, M and Punchbowl Creeks. Alternately crossing treeless plains and wooded flats in a west and then north-westerly direction the party reached the Leichhardt River (mistakenly identified by Leichhardt as the Albert [or Maet Suyker] River) on August 4 about 25 km north of 'Armraynald' homestead. However they were again required to travel south in search of freshwater and did not cross the Leichhardt River until they had reached a point about 20km WNW of 'Wernadinga' homestead. Heading in a north-westerly direction the party crossed Millar Creek and Beames Brook about 20km south-west of Burketown. All these streams flow into the Albert River but Leichhardt was just to the south of the major stream, which would have allowed for its identification. After a short distance they crossed the Nicholson River marking the end of expanses of open grassy plains.

June 26

On our way we passed some very fine long water-holes; some of which were surrounded with reeds [probably *Phragmites vallatoria*], and others covered with the white species of Nymphaea [possibly *Nymphaea macrosperma*][193]; groves of Pandanus spiralis [*Pandanus spiralis*][194] occupied their banks.

June 27

We travelled eight miles W.S.W. over a succession of plains separated by belts of forest, consisting of bloodwood [probably *Corymbia polycarpa*][195], box [*Eucalyptus microtheca, E. chlorophylla* or *E. tectifica*][196], apple-gum [*Corymbia confertiflora*][197], and rusty-gum [probably *Corymbia curtipes* or *C. terminalis*][198]. Some plains were scattered over with Bauhinias [*Bauhinia cunninghamii*][199].

The lagoon was covered with small white Nymphaeas, Damasoniums [*Caldesia oligococca* or *C. acanthocarpa*], and yellow Utricularias [*Utricularia aurea, U. gibba* or *U. muelleri*] ...

June 28

A small myrtle tree with smooth bark [*Asteromyrtus symphyocarpa*][200], and a leafless tree resembling the Casuarina [*Calycopeplus casuarinoides*], grew plentifully on its banks.

At the end of our stage, we came to a chain of shallow lagoons, which were slightly connected by a hollow. Many of them were dry; and fearing that, if we proceeded much farther, we should not find water, I encamped on one of them, containing a shallow pool; it was surrounded by a narrow belt of small tea trees, with stiff broad lanceolate leaves [probably *Melaleuca viridiflora*][201].

July 1

Box-tree flats of various sizes were separated by long tracts of undulating country, covered with broad-leaved tea-trees, Grevillea ceratophylla [*Grevillea parallela*][202], and G. mimosoides [*Grevillea striata*][203], and with the new species of Grevillea, with broad lanceolate leaves [*Grevillea mimosoides*][204]. We had to skirt several impassable thickets and scrubs of tea-tree [*Melaleuca* spp.][205], in one of which Pandanus abounded.

...fine water-holes covered with Villarsias [*Nymphoides crenata* or *N. indica*][206].

---

[193] See also June 27

[194] See also June 26, July 1, 2, 3, 4, 20, August 3

[195] See also July 4, 5, 20, 28, August 9, 20

[196] See also July 1, 2, 4, 5, 7, 8, 9, 12, 13, 14, 17, 19, 22, 23, 31, August 1, 2, 4, 9, 16, 18, 20

[197] See also July 4, 9, 12, 13, 20, August 1

[198] See also August 3, 4

[199] See also July 8, 13, 28

[200] See also July 2, when Leichhardt mentions 'clustered orange blossoms'

[201] See also July 1

[202] See also July 13

[203] See also July 7, 13, 25

[204] See also July 4

[205] See also July 1, 2, 3, 5, 7, 13, 14, 17, 18, 19, 20, 22, August 9

[206] See also August 20

July 2

I found Verticordia, a good sized tree [*Thryptomene oligandra*], and a Melaleuca with clustered orange blossoms and smooth bark, which I mentioned as growing on the supposed Nassau.

July 3

… some fine rocky water-holes, in which I discovered a yellow Villarsia [*Nymphoides crenata*], resembling in its leaves Villarsia inundata, R. Br.[207]

Pandanus was, as usual, very frequent; but a middle sized shady wide spreading tree, resembling the elm in the colour and form of its leaves, attracted our attention, and excited much interest. Its younger branches were rather drooping, its fruit was an oblong yellow plum, an inch long and half an inch in diameter, with a rather rough kernel [*Parinari nonda*][208]. When ripe, the pericarp is very mealy and agreeable to eat, and would be wholesome, if it were not so extraordinarily astringent. We called this tree the 'Nonda,' from its resemblance to a tree so called by the natives in the Moreton Bay district. I found the fruit in the dilli of the natives on the 21st June, and afterwards most abundantly in the stomach of the emu. The tree was very common in the belt of forest along the creek.

July 4

We travelled seven miles in a south-west direction, to lat. 16⁰ 15' 11", over an entirely flat country, covered with a very open forest of box, of bloodwood, and of the stiff-leaved Melaleuca, with the arborescent Grevillea already mentioned, and with a species of Terminalia with winged fruit [*Terminalia platyptera*]. In the more sandy tracts of bloodwood forest, grew the Nonda, the Pandanus, and the apple-gum. The shallow creek was surrounded by a scrub of various myrtaceous trees, particularly Melaleucas [*Melaleuca* spp.][209]. The creek afterwards divided into water-holes, fringed with Stravadium [*Barringtonia acutangula*][210], which, however, lower down gave way to dense belts of Polygonum [*Persicaria* sp.][211].

July 5

Tea-tree hollows extended along the outskirts of the plains. In one of them, we saw Salicornia [*Halosarcia indica, H. halocnemoides* or *H. pergranulata*][212] for the first time, which led us to believe that the salt water was close at hand. Having crossed the plains, we came to broad sheets of sand, overgrown with low shrubby tea-trees, and a species of Hakea [*Hakea arborescens*], which always grows in the vicinity of salt water.

Beyond the sands, we saw a dense green line of mangrove trees extending along a salt water creek…

July 7

…travelled two or three miles through a fine bloodwood and Nonda forest, the verdant appearance of which was much increased by the leguminous Ironbark [*Erythrophleum chlorostachys*][213], which grew here in great perfection.

We soon came to a salt-water river, with a broad sandy bed, perfectly free of vegetation, although its banks were fringed with drooping tea-trees [*Melaleuca argentea* or *M. leucadendra*][214].

A well grassed open forest extended along both sides of the river; and, at its left, large deep Nymphaea [*Nymphaea violacea, Nymphaea gigantea* or *N. macrosperma*][215] lagoons were parallel to it. South of the Staaten, we travelled over a forest country, similar to that of former stages, and which might be aptly distinguished by the name of Grevillea Forest; as Gr. mimosoides (*R. Br.*) is its characteristic feature; though a rather stunted stiff-leaved tea-tree [*Melaleuca nervosa, M. acacioides* or *M. citrolens*] was more numerous. Some slight rises were covered with thickets of the Acacia of Expedition Range [*Acacia bidwillii*].

---

[207] The name *Villarsia inundata* does not exist i.e. it was not published by Robert Brown, nor any other author

[208] See also July 4, 5, 7, 8, 19

[209] See also July 17, 19

[210] See also July 7

[211] See also July 9, 22, 23, August 2, 4, 6, 9

[212] See also July 18, 23, 25, 30, August 4

[213] See also August 20

[214] See also July 7, 9, 12, 17, 20, 28, August 18, 19, 20

[215] See also July 9, 17, 19, August 1, 20

We encamped on a good sized creek, on which grew the articulate podded Acacia [*Cathormion umbellatum*][216], the Mangrove Myrtle (Stravadium), and the drooping tea-tree.

July 8

…we passed a strip of Blackwood [*Corymbia polycarpa*][217] forest, with many Nonda trees; and crossed a small creek. The latter part of the stage was again over a large box-flat, intersected by shallow grassy depressions, timbered with flooded-gum [*Eucalyptus camaldulensis*][218]. We saw on the rising ground some open scrub, with scattered Bauhinias and Cochlospermums [probably *Cochlospermum gregorii*].

July 9

We travelled thirteen or fourteen miles south by west to latitude 17⁰ 0' 13", at first crossing a box-flat, and after that a succession of greater or smaller plains, separated by a very open Grevillea forest. These plains were well grassed, or partly covered with a species of Euphorbia [*Chamaesyce coghlanii* or *C. mitchelliana*], which was eaten by our horses and cattle; and also with the long trailings of the native melon [*Cucumis melo*]; the fruit of which tastes very tolerably, after the bitter skin has been removed; but when too ripe, the fruit is either insipid or nauseous.

The apple-gum, which we had missed for some time, again made its appearance, accompanied by another white gum, with long narrow leaves [possibly *Corymbia bella*][219]. As we approached the creek, at which we afterwards encamped, the vegetation became richer, and the melon-holes enlarged into dry water-holes, which were frequently shaded by the Acacia with articulate pods (Inga moniliformis). The two species of Terminalia [*Terminalia platyphylla, T. platyptera,* or *T. subacroptera*][220], of the upper Lynd, were numerous; and a small green looking tree, which we found growing densely along the creek, had wood of a brown colour, which smelt like raspberry jam [*Excoecaria parvifolia*][221]; and, upon burning it, the ashes produced a very strong lye, which I used in dressing the wounds of my companions. This tree was found in great abundance on all the rivers and creeks round the gulf, within the reach of salt water; and when crossing Arnheim Land, though less frequently.

July 12

We crossed a small river with a course west by north; it had a broad sandy bed, numerous pools of water, and steep banks: the latter were covered with Sarcocephalus [*Nauclea orientalis*][222] and drooping tea-trees.

Its water-holes were surrounded by the Nelumbiums of the Mackenzie [*Nelumbo nucifera*], and by a fine yellow Ipomoea, with larger flowers than that described as growing at the Mitchell [*Merremia gemella*]. We gathered a considerable quantity of Nelumbium seeds, which were very palatable, and, when roasted and pounded, made a most excellent substitute for coffee.

July 13

…a succession of plains of various sizes, extending mostly to the westward, and very open undulations scattered over with rather stunted trees of Grevillea mimosoides, G. ceratophylla, Terminalia, Bauhinia, and Balfouria? an apocynaceous tree [probably *Wrightia saligna*].

---

[216] See also July 9, 23, 28, 30, August 18

[217] Blackwood is a misprint. Leichhardt clearly wrote 'bloodwood' on the original hand written manuscript (Mitchell Library, Sydney)

[218] See also August 3

[219] See also July 12

[220] See also July 13, 31, August 2, 6, 19

[221] Jackes (1990) ascribed this to *Cathormion umbellatum,* which is currently known as the raspberry jam tree by some in the region today. However, the current usage of this name refers to the sap rather than the smell of the wood as referred to by Leichhardt. Furthermore Leichhardt's raspberry jam tree cannot be *Cathormion* as he has already clearly described that tree (see June 16). The habitat and distribution of *Excoecaria parvifolia* match very well that described by Leichhardt. The wood of *E. parvifolia* does have a sweet fruity smell, though not precisely like 21st century raspberry jam. The fact that Leichhardt failed to mention milky latex is the only point against this identification, but it is possible that the sap was not obvious during the middle to late dry season when the party travelled through the species' range. See also July 23, 24, 25, 28, 30, August 4, 8, 9, 16

[222] See also August 18, 19

July 18

…undulating Grevillea forest, which changed into tea-tree thickets, and stunted tea-tree scrubs, on a sandy soil with Salicornia, Binoe's Trichinium [probably *Omegandra kanisii*][223], and several other salt plants.

July 19

…a succession of stunted tea-tree thickets and tea-tree forests, in which the little bread-tree of the Lynd [*Gardenia vilhelmii*][224] was common.

The Nonda tree had disappeared north of the Van Diemen, and the emu here feeds on the fruit of the little Severn tree [*Petalostigma pubescens*][225], which is so excessively bitter, as to impart its quality to the meat, and even to the gizzard and the very marrow.

We now commenced collecting the gum of the broad-leaved Terminalia [*Terminalia platyphylla*][226] of the upper Lynd…

July 20

…hills were composed of iron-sandstone; their summits were generally very openly timbered with apple-gum and a new white-barked tree[226a]; but their bases were covered with thickets of the little Severn tree. The intervening flats bore either a box-tree with a short trunk branching off immediately above the ground [*Eucalyptus chlorophylla* or *E. microtheca*]; or a middle-sized tea-tree, with a lanceolate leaf [possibly *Melaleuca nervosa*], or thickets of stunted tea-tree. We travelled full thirteen miles without water, or any decided water-course. We passed several dry water-holes shaded by the broad-leaved Terminalia; and saw many Acacias twenty-five and thirty feet in height, with a slender trunk, and an elegant drooping foliage [*Acacia sutherlandii*]: it very much resembled the Acacia of Expedition Range; but the drooping habit and more distant leaflets of its bipinnate leaves, showed at once their difference.

July 23

Salicornia grew along the small gullies into which the tide flowed; some struggling stunted mangroves were on the opposite side; and the plains along the right side of the river were occupied by a scanty vegetation, consisting of Phyllanthus shrubs [probably *Flueggea virosa*], scattered box, and the raspberry-jam trees.

July 25

I passed some low stunted forest, in which a small tree was observed, with stiff pinnate leaves and a round fruit of the size of a small apple, with a rough stone [*Owenia reticulata*], and a very nauseous rind, at least in its unripe state. To the westward of this belt of forest, we crossed extensive marshes covered with tender, though dry grass, and surrounded by low Ironstone ridges, openly timbered with stunted silver-leaved Ironbark [*Eucalyptus pruinosa*][227], several white gums [*Eucalyptus leucophloia* or *Corymbia capricornia*], and Hakea lorea, *R. Br.* [*Hakea lorea*] in full blossom. We had not seen the latter for a long time, although Grevillea mimosoides, with which it was generally associated, had been our constant companion.

July 28

In turning again towards the river, we crossed a large plain, from which pillars of smoke were seen rising above the green belt of raspberry-jam trees which covered the approaches to the river. After passing some forest of Moreton Bay ash [*Corymbia bella*][228], bloodwood, clustered box [*Eucalyptus chlorophylla* or *E. microtheca*][229], Acacia (Inga moniliformis), and a few Bauhinias, we came to another salt-water creek…

---

[223] *Trichinium* is an old name for *Ptilotus*, and the recently described *Omegandra* was confused with *Ptilotus murrayi*. Unfortunately the reference to Bynoe has not been resolved. There are no Leichhardt or Bynoe specimens in the herbaria at Kew or the British Musuem for either *Omegandra kanisii* or *P. murrayi*. Leichhardt always mentioned this species in relation to saltmarsh, i.e. with Salicornia. *Omegandra kanisii* seems to be the only likely candidate that has the correct habitat. See also July 24, 30, August 4

[224] See also July 20

[225] See also July 20, August 1, 20

[226] See also July 20, 30, August 9, 18

[226a] Leichhardt's route notes (Leichhardt 1844–45) indicate that this 'new white-barked tree' had opposite leaves. The identity of this tree is unknown

[227] See also July 30, 31. August 1, 2, 3, 8, 9

[228] Some forms of *C. bella* with rough basal bark resemble *C. tessellaris*, the Moreton Bay Ash

[229] See also July 30

July 31

A fine plain extended along it, on which I observed Acacia Farnesiana [*Acacia farnesiana*] of Darling Downs, the grass of the Isaacs [*Heteropogon triticeus*], and several grasses of the Suttor. The holes of the creek were shaded by large Terminalias, and by a white gum, with slightly drooping foliage of a pleasing green colour [*Eucalyptus camaldulensis*][230].

August 2

Brown collected a good quantity of the gum of Terminalia, and the seeds of the river bean [probably *Canavalia papuana*][231], which made an excellent coffee.

August 3

…passed over ironstone ridges covered with stunted silver-leaved Ironbark; and a species of Terminalia, a small tree, with long spathulate glaucous leaves, slightly winged seed-vessels [*Terminalia canescens*], and with an abundance of fine transparent eatable gum…

A native had carved a representation of the foot of an emu in the bark of a gum-tree [probably *Eucalyptus camaldulensis*][232]…

August 4

In a patch of rusty-gum forest we found Acacia equisetifolia [possibly *Acacia galioides*][233], and the dwarf Grevillea of the upper Lynd [*Grevillea dryandri*] in blossom; the thyrsi of scarlet flowers of the latter were particularly beautiful.

August 6

The rough-leaved fig tree [*Ficus opposita*], the white cedar [*Melia azedarach*], and a stiff-leaved Ipomoea with pink blossoms [probably *Ipomoea gracilis*][234], grew on its sandy banks; and some low straggling mangroves at the water's edge.

…a good supply of Convolvulus roots [possibly *Ipomoea gracilis* or *I. brassii*], and of Terminalia gum behind them.

August 8

The salt-water Hibiscus, a species of Paritium, *Adr. Juss.* (Hibiscus tiliaceus? *Linn. D.C. Prodr. I. p. 454*) [*Hibiscus tiliaceus*] grew round the water-holes. We found the same little tree at the salt-water rivers on the west coast of the gulf, and at Port Essington. I had formerly seen it at the sea coast of Moreton Bay; its bark is tough and fibrous, and the heart-wood is brown with a velvety lustre.

August 18

…a creek in which we recognised a Casuarina [*Casuarina cunninghamiana*][235], which tree we had not seen since we left the Mitchell.

A narrow belt of brush, with drooping tea-trees, the Corypha palm [*Livstona rigida*][236], the Pandanus [*Pandanus aquaticus*][237], and Sarcocephalus, grew along the water's edge.

August 19

The plains were well-grassed, but full of melon-holes. I observed on them a few small trees, belonging to the Sapindaceae, with pinnate and rather drooping leaves, with a light grey bark [*Atalaya hemiglauca*], exuding a good eatable gum.

---

[230] See also August 1, 2, 3

[231] See January 14

[232] See also August 4

[233] We have assumed that the unpublished name *A. equisetifolia* refers to a plant having whorled leaves like *Equisetum*. However, he uses the name on the second expedition (6th January) [see Sprod 1989, p. 148] in the vicinity of Barakula State Forest, where no *Acacia* of this form is known to occur.

[234] There is a form of *Ipomoea gracilis* probably deserving specific rank with rather 'stiff leaves' that occurs in a limited area precisely where Leichhardt made this record (R. Johnson pers. comm.)

[235] See also August 19

[236] See also August 19

[237] On September 6, Leichhardt refers to 'water Pandanus, which we first observed at Beame's Brook'. See also August 19

Section 9. Western Gulf of Carpentaria (August 21-October 20 1845)

For this leg of the journey the party was following the coast of the Gulf of Carpentaria in a north-westerly direction. Beyond the Nicholson River, Melaleuca *species typically dominate and the party altered their course in order to avoid the scrubbier sections. Making relatively rapid progress they crossed a succession of minor streams including Eight Mile Creek (Leichhardt's Turner's Creek), which they reached on September 2. At this point they were within 10km of the coast of the Gulf of Carpentaria and on the edge of the coastal salt-flats. Seeking to avoid this waterless country they adjusted their route to the south-west for a day, and re-entered the Melaleuca forest. Travelling just north of west they crossed Lagoon Creek, Settlement Creek (Leichhardt's Wentworth Creek) and Camel Ck before crossing the Northern Territory border on September 6. Their route was in mostly flat terrain behind the tidal zone but there were occasional sandy ridges with stringybark forest and belts of cypress pine. The major streams that they crossed were the Calvert River (Leichhardt's Van Alphen River), the Robinson River (Leichhardt's Abel Tasman Creek) and the Macarthur River. The latter was forded on September 26 not far upstream of Borooloola. In this area they came in contact with aboriginal people who were familiar with knives and guns presumably as a result of interchange with Maccasan seamen from Indonesia. On October 6 they reached the Limmen Bight River where the killing of an exhausted bullock required Leichhardt to abandon his paper for drying plants, duplicate zoological specimens, and his rock and wood specimens. When the party reached the Roper River at the south-western corner of the Gulf of Carpentaria they headed upstream in a westerly direction and left the coast for the last time before their destination.*

August 22

The composition of the scrub depended on the nature of the soil. The narrow-leaved tea-tree [probably *Melaleuca citrolens* or *M. acacioides*], in shrubs from five to seven feet high, and the broad-leaved tea-tree [*Melaleuca viridiflora*][238] from twenty to twenty-five feet high, grew on a sandy loam, with many ant-hills between them; the little Severn tree [*Petalostigma pubescens*][239] and the glaucous Terminalia [*Terminalia canescens*][240] preferred the light sandy soil with small ironstone pebbles, on which the ant-hills were rare, or entirely wanting; the raspberry-jam tree [*Excoecaria parvifolia*][241] crowded round water-holes, which were frequently rocky; and the bloodwood [probably *Corymbia polycarpa*][242], the leguminous Ironbark [*Erythrophleum chlorostachys*][243], the box [*Eucalyptus microtheca*, *E. tectifica* or *E. chlorophylla*][244], and apple-gum [*Corymbia confertiflora*][245], formed patches of open forest.

August 25

Here we passed several tea-tree [*Melaleuca* sp.][246] swamps, dry at this time, level, like a table, and covered with small trees, and surrounded by a belt of fine box-trees and drooping water-gum trees [*Eucalyptus camaldulensis*][247].

…came at last to a creek and to a small river, along which we travelled until darkness compelled us to encamp. It had fine water-holes, and was densely shaded with drooping tea-trees [*Melaleuca argentea* or *M. leucadendra*][248]…

We moved our camp to this lagoon, which was covered with Villarsia leaves [*Nymphoides crenata* or *N. indica*][249]…

The apple-gum, the box, and the Moreton Bay ash [*Corymbia bella*] composed a very open well-grassed forest…

---

[238] See also August 25, 27, 28, September 6, 7, 11, 15, 19, 21, 29, October 12, 15

[239] See also August 25, September 24

[240] Probably the species that provided gum, as referred to later in this passage: 'We collected a great quantity of Terminalia gum, and prepared it in different ways to render it more palatable. The natives, whose tracks we saw everywhere in the scrub, with frequent marks where they had collected gum—seemed to roast it.'

[241] See also September 11, October 18, 19, 20

[242] See also August 27, September 2, 5, 6, 8, 9, 14, 16, 19, 24

[243] See also September 5, 9, 14, 21, October 15

[244] See also August 25, September 4, 8, 10, 15, 18, 21, 24 October 9, 14, 15, 17, 19, 20

[245] See also August 25, September 5, 8

[246] See also August 27, 28, September 2, 3, 5, 6, 12, 13, 14, 16, 18, 19, 21, 24, 27, 29, October 2, 9, 14, 15, 16, 17

[247] See also September 4, 21

[248] See also August 29, 30, September 3, 4, 5, 6, 8, 12, 19, 21, 27, 29, October 13, 14, 18, 19

[249] See also August 27

August 27

Half way we crossed a broad watercourse, with long tracks of burnt grass. The Pandanus [probably *Pandanus spiralis*][250] and the bloodwood grew on its limited flats.

…a deep pool of water, covered with Villarsia leaves, and surrounded by Polygonums [*Persicaria* sp.][251].

August 29

A low shrubby Acacia with sigmoid phyllodia [*Acacia wickhamii*] was frequent on the hills.

The crops of the large cockatoos were filled with the young red shoots of the Haemodorum [*Haemodorum coccineum*], which were almost as pungent as chillis, but more aromatic; the plant abounded on the sandy soil.

August 30

Salicornia [*Halosarcia indica, H. halocnemoides* or *H. pergranulata*][252] grew in abundance…

September 2

…passing some of the usual tea-tree scrub, to an undulating country, with scattered shrubs of the salt water tea-tree [*Melaleuca acacioides*][253], which grew particularly on the sandy heads of salt water creeks.

It was on this stage that we first met with a leafless species of Bossiaea, from three to five feet high, with compressed stem, and branches of the habit of Bossiaea scolopendrium, with yellow blossoms, and smooth many-seeded pods little more than an inch long [probably *Bossiaea bossiaeoides*][254]. This shrub was one of the principal components of all the scrubs we passed from this place to Limmen Bight, and was also found, though less frequently, towards the centre of Arnheim's Land.

September 3

But we crossed four good sized dry creeks, lined with drooping tea-trees and white-gum [*Eucalyptus camaldulensis*][255] trees.

September 4

After crossing a small sandy creek, along which grew a few Sarcocephalus [*Nauclea orientalis*][256]…

September 5

…came to a thick stringy-bark [*Eucalyptus tetrodonta*][257] forest, on a sandy soil, with a hard sandstone cropping out frequently.

But, from the broken pieces of granite of our last camp, it became evident that a rocky primitive country, like that of the upper Lynd, could not be very distant. Even the vegetation agreed well with that of the same locality; as the dwarf Grevillea, G. chrysodendrum [*Grevillea pteridifolia*][258], and the falcate Grevillea [*Grevillea mimosoides*] of the upper Lynd, were here again observed.

---

[250] See also August 27, 30, September 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16, 18, 19, 24, 26, 27, October 2, 9, 14, 15, 17

[251] See also September 13, October 19

[252] See also September 2, 15, 16, October 6, 18

[253] See also October 6 where Leichhardt more fully describes this species as having 'an odour very much resembling that of a Blackfellow'

[254] See also September 10, 29, October 2

[255] Also referred to as 'white water-gum'. See also September 4, 15, 16, 21

[256] See also September 4, 24

[257] See also September 6, 7, 8, 9, 10, 11, 14, 19, 20, 21, 27, 29, October 2, 9, 15, 17

[258] See also September 6, 8, October 14

September 6

This channel was fringed with the water Pandanus [*Pandanus aquaticus*][259], which we first observed at Beames's Brook; the sandy bed was covered with drooping tea-trees and Grevillea chrysodendrum. Charley shot a bustard, the stomach of which was filled with seeds of Grewia [*Grewia retusifolia*], with small yellow seeds, and some beetles.

September 7

... covered with white [*Nymphoides indica*] and yellow Villarsias [*Nymphoides crenata*] and yellow Utricularias [*Utricularia aurea, U.gibba* or *U.muelleri*]. The rose-coloured Sterculia [*Brachychiton paradoxus*][260], and a smooth broad-leaved Terminalia [*Terminalia platyphylla*][261], were observed on the sandy flats of the creek; and a small fan-leaved palm (Livistona humilis, *R. Br.*) [*Livistona inermis*], a small insignificant trunkless plant, growing between sandstone rocks, was here first observed. A taller species of this palm [probably *Livistona humilis*], as we subsequently found, formed large tracts of forest on the Cobourg Peninsula, and near the Alligator rivers.

September 8

The first and last parts of the stage were scrubby, or covered with a dense underwood of several species of Acacia, Grevillea chrysodendrum and a species of Pultenaea with leafless compressed stem [*Leptosema bossiaeoides* or *Jacksonia dilatata*][262].

In the scrub, I again observed Fusanus [*Owenia reticulata* or *O. vernicosa*] with pinnate leaves.

The well-known kangaroo grass (Anthisteria)[*Themeda triandra*] forms still one of the principal components of the pasture.

Xyris [probably *Xyris complanata*], Philydrum [*Philydrum lanuginosum*] a species of Xerotes[263] and an aromatic spreading herb [probably *Limnophila fragrans*], grew in great abundance round the water.

A species of Crotolaria two or three feet high, with simple woolly oblong or oblongo-lanceolate leaves, and with a beautiful green blossom [*Crotalaria cunninghamii*] of the form and size of that of Kennedya rubicunda, grew in the bed of the river.

September 9

Its flats were well-grassed, and very openly timbered with bloodwood, stringy-bark, leguminous Ironbark then in blossom, and a large tree with white smooth bark, spreading branches, and pinnate leaves [probably *Canarium australianum*]. The salt water Hibiscus (Paritium) [*Hibiscus tiliaceus*][264] and Acacia (Inga moniliformis)[*Cathormion umbellatum*], were also in blossom.

September 10

At the left side of the river, we saw four or five fine Cycas palms [*Cycas angulata*][265], from eight to ten feet high, and the stem from six to nine inches in diameter.

The appearance of the Cypress pine [*Callitris intratropica*][266], which formed groups within the stringy-bark forest, and particularly on the rises and sandy slopes, was of a most striking character. A new species of Grevillea [possibly *Grevillea heliosperma*] and also of Calythrix [*Calytrix exstipulata* or *C. brownii*] were found in blossom.

September 13

...interrupted by three creeks, the first dry, the second with pools of brackish water, and the third with chains of Nymphaea [*Nymphaea violacea* or *N. macrosperma*][267] ponds within and parallel to its bed.

---

[259] See also September 29, October 19

[260] See also September 20, 12, 22, 24, 27, 29

[261] See also October 18

[262] See also October 2

[263] *Xerotes* is synonymous with *Lomandra*, but no species of *Lomandra* occur in this part of Australia.

[264] See also October 19

[265] See also September 15, 16, 18, 19

[266] See also September 10, 11, 13, 15, 16, 18, 19, 21, 24, 27, 29, October 2, 16, 17

[267] See also September 24, October 2, 9, 11, 12, 13, 18

September 15

The foot-path conducted us from one Zamia [*Cycas angulata*] grove to another…

September 19

Here we again observed the gum-tree with orange blossoms and large ribbed seed-vessels, which we found at the upper Lynd, and had called Melaleuca gum [*Eucalyptus miniata*][268].

September 22

By a mere accident, we discovered a remarkable medicinal property of the glutinous secretion of the seed-vessels of a drooping Grevillea [possibly *Grevillea mimosoides*].

September 24

The bean [*Canavalia papuana*] of the Mackenzie grew plentifully along the river, and was covered with ripe seeds.

…we came again into the open box and tea-tree forest, mixed with bloodwood and gum.

It was here that I again met with a species of Banksia [*Banksia dentata*], on the sandy flats immediately below the sandstone ranges, which was either a variety of B. integrifolia, or a species very nearly allied to it.

Brown and John had returned with a good supply of beans, and of the large eatable roots of a Convolvulus [probably *Ipomoea brassii*] growing on the plains.

September 29

Acacia neurocarpa [*Acacia holosericea* or *A. neurocarpa*][269] and a species of Cassia [*Senna oligoclada, S. costata* or *S. planitiicola*], which we had observed since leaving Seven Emu River, grew on the sands.

…came sooner than I expected to Sterculia Creek: which name I had given to the creek on which we were encamped, in reference to the groves of Sterculias of both species, rose-coloured as well as heterophylla [*Brachychiton diversifolius*], which grow on its banks.

October 2

It was during this stage, and among the scrub and underwood of the sandy hills, that we first met with Grevillea pungens (*R. Br.*)[*Grevillea pungens*], a shrub from two to five feet high, with pale-green pinnatifid pungent leaves, and racemes of red flowers. Flagellaria indica *L.* [*Flagellaria indica*][270], was very abundant near the creek; and our bullocks fed heartily upon it: particularly in this most wretched country, where the grass was scanty and hard.

October 9

We observed some springs, with but little water however, though densely surrounded with ferns (Osmunda) [probably *Cyclosorus interruptus*]. After about seven miles, we were stopped by a fern swamp full of fine box-trees with a thick jungle of high stiff grasses and ferns (Blechnum)[probably *Blechnum orientale*]. A small running creek formed its outlet, and contained a chain of deep ponds covered with Nymphaeas with the latter species most common and surrounded with Typha (bull-rush) [probably *Typha domingensis*][271], the youngest part of the leaves of which is very tolerable eating.

October 10

A species of Hibiscus [*Hibiscus zonatus*] with large pink flowers, but small insignificant leaves, and another small malvaceous shrub [possibly *Abelmoschus moschatus*] with white flowers grew round the camp.

---

[268] See also September 27

[269] See also October 14

[270] See also October 3, 12, 19

[271] See also October 12, 13, 17

October 12

…we arrived at a creek with a fine pool of water, which, notwithstanding its Nymphaeas, Charas [*Chara* sp.], and Typhas, was slightly brackish and bitter.

October 14

At the end of the stage, the uniform colour of the country was interrupted by the green line of a river-bed, so pleasing and so refreshing to the eye, with the rich verdure of its drooping tea-trees and myrtles [probably *Asteromyrtus symphyocarpa*]…

Brown found a Eugenia with large white blossoms and large coriaceous oblong lanceolate shining leaves; it was a tree of thirty or forty feet high, with a grey bark, and a good hard wood. It was growing at the upper part of the creek on which we were encamped last night. Its fruit was two inches in diameter, with longitudinal ribs, scarlet red, and very eatable when dropt from the tree, but when gathered on the tree, it had an aromatic pungency [*Syzygium suborbiculare*]. This tree was very common along the well watered creeks of Arnheim's Land; particularly along the South Alligator River, and at Raffles Bay. Brown brought from the same locality a Melastoma [*Melastoma malabathricum*] which, according to him, was a shrub, three or four feet high.

October 17

We followed a very promising Pandanus creek, in which the presence of Typha (flag, or bulrush) and a new species of Sesbania [probably *Sesbania formosa*] indicated the recent presence of water.

October 18

Salicornia and Binoe's Trichinium [probably *Omegandra kanisii*][272] indicated the neighbourhood of salt water; but the grass was good and mostly young.

October 19

Casuarinas [*Casuarina cunninghamiana*] drooping tea-trees, the mangrove myrtle (Stravadium) [*Barringtonia acutangula*] and raspberry-jam trees grew either on the flats, or formed open groves along the banks...

When we came to the end of the lagoon, which was bounded on the left by a stony rise of flaggy Psammite, I observed a green belt of trees scarcely 300 yards to the northward; and on riding towards it, I found myself on the banks of a large fresh water river from 500 to 800 yards broad, with not very high banks, densely covered with salt water Hibiscus (Paritium), with a small rubiaceous tree (Pavetta?) [probably *Pavetta brownii*], which filled the air with the jasmine-like fragrance of its blossoms; with Flagellaria, water Pandanus and a leguminous climber with bunches of large green blossoms (Mucuna?—*D.C. Pr.*) [*Mucuna gigantea*].

Section 10. Arnhem Land plateau
(October 21 - November 20 1845)

The section started disastrously for Leichhardt with the drowning of four of the pack animals in the Roper River and as a consequence, the discarding of the major part of his botanical collection. They continued up the Roper, crossing the many tributaries, including the Wilton River, which flows from the southeastern slopes of the Arnhem Land Plateau. The sandstone plateau is highest in the north-west and dips towards the east and south where it merges with the surrounding terrain. Thus the rugged nature of the country they were entering would not have been obvious as they left the Roper on October 28 to head north-west up Flying Fox Creek. From the watershed at the headwaters of this stream they continued north-west to Snowdrop Creek (so named for a favourite bullock which was butchered there), close to the plateau summit. The plateau is mostly exposed sandstone but on level areas there is heath on shallow sand and forests in infilled gullies with deeper sand. There are also remnants of the lateritic surface, which originally overlaid the sandstone, that support stringybark forest akin to the lowlands. The intense heat of the late dry season and the rugged terrain must have severely tested the exhausted and footsore men and their animals. Following Snowdrop Creek to its junction with the Katherine River they travelled north-west to Gimbat Creek where they entered Kakadu National Park. Following this creek through rugged sandstone they found a descent from the plateau down the steep escarpment probably to the west of Twin Falls.

---

[272] See discussion for July 18

October 21

Open box-flats [probably *Eucalyptus tectifica*][273] were bounded by ridges two or three miles from the river. At the opposite side, ranges were seen with some rocky bluff hills.

October 22

About two miles and a-half from our last camp, we had to cross a running Casuarina [*Casuarina cunninghamiana*][274] brook…

October 23

…the creek formed a dry sandy bed, covered with Casuarinas; it was joined by two Pandanus [probably *Pandanus spiralis*][275] creeks with steep deep channels…

About a mile up the river, a ledge of rocks crossed the bed, over which a considerable stream formed a small fall and rapids; above this was a fine sheet of water, overhung with shady tea-trees [probably *Melaleuca argentea* or *M. leucadendra*][276], Casuarinas, and Pandanus…

October 24

I gathered the large vine-bean [*Mucuna gigantea*] with green blossoms, which had thick pods containing from one to five seeds. Its hard covering, by roasting, became very brittle; and I pounded the cotyledons, and boiled them for several hours. This softened them, and made a sort of porridge, which, at all events, was very satisfying.

October 25

The country was well grassed, and openly timbered with white gum [probably *Corymbia bella*][277], box, and leguminous Ironbark [*Erythrophleum chlorostachys*][278] but occasionally broken by deep gullies, which were fringed with the articulate-podded Acacia (Inga moniliformis)[*Cathormion umbellatum*][279], and the broad-leaved Terminalia [*Terminalia platyphylla*][280].

Thick high reeds [*Phragmites vallatoria*][281] covered the approaches of the river, and the lower parts of the gullies; and noble Casuarinas rivalled the drooping tea-tree [*Melaleuca argentea* or *M. leucadendra*][282] in beauty. Grevillea pungens (*R. Br.*)[*Grevillea pungens*] was observed on the hills; it is, therefore, not particular to the coast scrub. A species of native tobacco with smaller blossoms than that of the Hunter, and with its radical leaves spreading close over the ground [possibly *Nicotiana megalosiphon*], was growing on the open spaces round the water-holes.

October 26

As we approached the river, we passed some sandstone hills covered with a dense scrub exactly like that of the sea coast south of Limmen Bight. It was principally composed of several species of Acacia of Grevillea chrysodendron (*R. Br.*)[*Grevillea pteridifolia*], and of the Bossiaea with broad stem [*Bossiaea bossiaeaoides*]. All along the outside of the scrub, we observed old camps of the natives; several of whom were seen crossing the plains.

The bed of the river became excessively wild: the Pandanus channel was still full of water, and running; but the dry bed was full of rocky water-holes or chains of them, composed of, and scattered over with blocks of sandstone; and overgrown with most magnificent Casuarinas with tea-trees [*Melaleuca* spp.][283] and flooded-gum [probably *Eucalyptus camaldulensis* or *Corymbia bella*] (or its representative).

---

[273] See also October 22, 25, 29, 30
[274] See also October 23, 25, 26
[275] See also October 23, 26, 27, 30, November 1, 2, 3, 6, 10, 14, 16, 20
[276] See also October 26
[277] See also October 30, November 20
[278] See also November 6
[279] See also October 30
[280] See also November 3, 20
[281] See also November 1
[282] See also November 1, 2, 3, 6, 10, 14, 19
[283] See also November 1, 5

October 28

We now followed the direction of some smoke which rose behind a large mountain; passing on our way, over an undulating country clothed with a forest of the broad-leaved tea-tree [*Melaleuca viridiflora*][284]; and a scrubby flat with large melon-holes fringed with raspberry-jam trees [*Excoecaria parvifolia*] and through a gap between two high ranges, in which there was a small dry creek that turned to the north-east. From a large Polygonum [*Persicaria* sp.] water-hole which had recently become dry, a swarm of whistling ducks rose, probably scared by our approach.

October 29

The Acacia of Expedition Range was plentiful in the large flat and at the wells of the natives, and formed a fine tree [*Acacia valida*]: its seeds, however, were shed, and had been roasted by the late bush fire.

October 30

It was fringed with Pandanus, Acacia (Inga moniliformis) and with an arborescent Vitex with ternate leaves [*Vitex glabrata*].

On the flat summit of the sandstone ranges, we observed the Melaleuca gum [*Eucalyptus miniata*][285], the rusty gum [*Corymbia* sp.][286] , the mountain Acacia [possibly *Acacia valida*][287], and Persoonia falcata, (*R. Br.*)[*Persoonia falcata*][288].

During the night, a great number of flying-foxes came to revel in the honey of the blossoms of the gum trees [*Eucalyptus* sp.][289].

October 31

I found a species of fern (Taeniopsis) [possibly *Lindsaea ensifolia* or *Taenitis blechnoides*] along the creek, and a species of Mimosa [probably *Neptunia major*] about three feet high had been observed on the plains and the flats of the Roper.

November 1

It was a broad creek, with a stream about three feet deep, and from seven to ten yards wide, with a firm and sandy bed; its banks were shaded by large gum-trees, and Sarcocephalus [*Nauclea orientalis*][290] and thick reeds, and a stiff blady grass fringed its waters.

November 2

The creek wound between baked sandstone hills, and was alternately enlarging into Nymphaea [*Nymphaea violacea* or *N. macropserma*] [291] ponds, and running in a small stream over a pebbly or sandy bed. Pandanus, drooping tea-trees, Terminalias [*Terminalia platyphylla, T. erythrocarpa* or *T. microcarpa*.], Acacias [*Acacia* sp.], and Sarcocephalus gave it a rich green appearance. The apple-gum [*Corymbia confertiflora*][292] and Eugenia with ribbed scarlet fruit [*Syzygium suborbiculare*][293], grew on the flats. Methorium *Endl.* was found, in leaf and size resembling the hazel-nut; it had showy red and white blossoms [probably *Helicteres isora*]. The clustered fig-tree [*Ficus racemosa*] was abundant along the creek; but its ripe fruits were rare at this time of the year.

---

[284] See also October 29

[285] See also November 5, 6, 10, 11, 14, 17

[286] See also November 4

[287] See also November 4

[288] See also November 14

[289] See also October 30, November 1

[290] See also November 2, 3

[291] See also November 2, 3, 4, 5

[292] See also November 4, 7

[293] See also November 13

November 3

Polyphragmon [*Timonius timon*], which was first met with at the upper Lynd; Careya arborea [*Planchonia careya*][294], Hakea arborescens [*Hakea arborescens*], and Coniogeton arborescens [*Buchanania obovata*][295], were observed.

November 4

The whole valley, though narrow, was beautifully grassed. Trichodesma [*Trichodesma zeylanicum*], Grewia [probably *Grewia retusifolia*][296], Crinum [probably *Crinum uniflorum*][297], and the trefoil of the Suttor[298], grew on the flats; the apple-gum, rusty-gum, the mountain Acacia and Fusanus [*Owenia vernicosa* or *O. reticulata*][299], the last in blossom, grew on the ridges.

November 5

After following the creek, on which we had encamped, to its head, we passed over a scrubby stringy-bark [*Eucalyptus tetrodonta*][300] forest; and, whenever we came to watercourses going to the eastward, we turned to the north-west and westward.

We, therefore, followed a watercourse to the southward, winding between two ranges to the westward and southward, and continued again to the north-west, which brought us to a tributary of the creek we had just left, and in which we found large water-holes covered with Nymphaeas and Villarsias [probably *Nymphoides indica*].

The Melaleuca-gum, the Cypress-pine [*Callitris intratropica*][301], Fusanus [possibly *Owenia vernicosa*] and Banksia [*Banksia dentata*][302] abounded in the stringy-bark forest, and along the creeks; and the flats round the water-holes were covered with a dark green sedge [possibly *Dapsilanthus spathaceus*], which, however, our cattle did not relish so much as, from its inviting verdure, I had anticipated would have been the case.

November 6

The ridges at the head of this western creek were covered with an arborescent Capparis [*Capparis umbonata*], the ripe fruit of which tasted very like strawberries; but those which were not ripe were very pungent. Another little tree belonging to the Hamelieae *D.C.*, with large white fragrant blossoms, and fruit about two inches long and one broad, with numerous seeds nestling in a pulpy substance [probably *Gardenia megasperma*], was very abundant. In its ripe state, the pulp turned black; I ate some of it, but although it proved to be harmless, it was not good. The little bread-fruit of the upper Lynd, no doubt belonged to the same class of plants.

November 7

The apple-gum, a bloodwood [possibly *Corymbia polycarpa*] and the poplar-gum (?) [*Eucalyptus bigalerita* or *E. tintinnans*] grew round our camp; the grasses were tender, but formed distinct tufts; Crinum [*Crinum angustifolium*] was plentiful.

November 9

A pretty little Sida [*Sida* sp.], a Convolvolus [possibly *Merremia incisa* or *Polymeria ambigua*], and Grewia, were growing amongst the young grass. Mr. Calvert saw the Livistona palm [*Livistona inermis*].

November 11

A fine shady Eucalyptus [*Allosyncarpia ternata*][303], with a short barrel, but large spreading branches, and with the grey bark of the box, grew between the rocks along the creek.

---

[294] See also November 20

[295] See also November 16, 20

[296] See also November 9

[297] See also November 7

[298] Leichhardt makes no reference to a 'trefoil' when in the Suttor River area

[299] See also November 5

[300] See also November 5, 6, 11, 14

[301] See also November 9

[302] See also November 10, 14, 17

[303] See also November 19.

November 13

The flying-fox lived here on a small, blue, oval stone-fruit, of an acid taste, with a bitter kernel; it grew on a tree of moderate size [*Elaeocarpus arnhemicus*]. Very small specimens of the Seaforthia [*Hydriastele wendlandiana*] palm were here observed for the first time…

November 14

John told me that he had found the ripe fruit of Exocarpus cupressiformis; which I doubted very much, as I had not seen the slightest trace of it since we left the Dawson, although Exocarpus latifolia [*Exocarpos latifolius*] was very frequent all over the sandy table-land. But we gathered and ate a great quantity of gibong (the ripe fruit of Persoonia falcata), and some small yellow figs of the glossy-leaved fig-tree [probably *Ficus virens*]. I observed a Eucalyptus of rather stunted growth, with broad, almost oval leaves, and long, narrow seed-vessels [*Eucalyptus phoenicea*].

November 19

I appeased my craving hunger, which had been well tried for twenty hours, on the small fruit of a species of Acmena [possibly *Syzygium eucalyptoides* subsp. *eucalyptoides*] which grew near the rocks that bounded the sandy flats, until my companions brought my share of stewed green hide.

November 20

In the rocky gullies of the table land, we had observed a great number of shrubs, amongst which a species of Pleurandra [*Hibbertia* sp.], a dwarf Calythrix [probably *Calytrix decussata*], a prostrate woolly Grevillea [*Grevillea rubicunda*]; and a red Melaleuca [*Petraeomyrtus punicea*], were the most interesting. Near the slope by which we entered the valley, a species of Achras [probably *Pouteria sericea*] was found, but with a much smaller fruit than that of Port Jackson.

Section 11. Top End lowlands (November 22-December 17 1845)

With the sandstone escarpment behind them, the party met Jim Jim Creek, which they followed until they reached the coastal floodplain of the South Aligator River. Some aboriginal people pointed them in a roughly northerly direction through open forest on lateritic plains. On this course they crossed catchments emerging onto the floodplain of the East Alligator River far too near the coast to allow for a crossing. Camped near Van Diemen Gulf on December 1 and 2 their spirits were lifted by further meetings with aboriginal people that spoke some English. They guided them south-east to a safe crossing of the East Alligator on December 6 at the bar known as Cahills Crossing. From here they headed northward across the floodplain and came upon herds of recently naturalised Asian water buffalo. Further amicable interchanges with curious aboriginal people guided them to the narrow neck that joins Cobourg Peninsula to the mainland. Amidst the excitement as their journey neared its end they mistakenly detoured around the convoluted northern coastline of the Cobourg Peninsula before eventually arriving at their desired destination, the small outpost of European civilization at Victoria Settlement on the southwestern side of Port Essington.

November 23

The Eugenia with scarlet fruit [*Syzygium suborbiculare*][304], and another species with rose-coloured fruit [*Syzygium eucalyptoides* subsp. *bleeseri*][305] of most exquisite taste—particularly when the seed was abortive, and the pericarp more developed—were abundant on the flats of the river; and Acmena with smaller fruit and thin acidulous rind [possibly *Syzygium eucalyptoides* subsp. *eucalyptoides*], grew straggling on the ridges.

November 24

The river gradually increased in size, and its bed became densely fringed with Pandanus [*Pandanus spiralis*][306]; the hollows and flats were covered with groves of drooping tea-trees [*Melaleuca* spp.][307].

---

[304] See also November 25, December 2, 8, 16

[305] See also December 2

[306] See also November 24, 26, 27, 30, December 1, 3, 4, 8, 10, 14

[307] See also November 24, 27, December 3, 8, 9, 10, 14, 15, 17

November 25

The Livistona palm [*Livistona humilis*][308] and Coehlospermum gossypium [*Cochlospermum fraseri*][309] grew on the ridges; the tea-tree [*Melaleuca* sp.][310], the stringy-bark [*Eucalyptus tetrodonta*][311], the leguminous Ironbark [*Erythrophleum chlorostachys*][312] and Eugenia were useful timber.

November 26

Livistona inermis [*Livistona humilis*][313], R. Br. formed small groves…

We crossed the plain to find water, but the approaches of the river were formed by tea-tree hollows, and by thick vine brush, at the outside of which noble bouquets of Bamboo [*Bambusa arnhemica*] and stately Corypha palms [*Livistona benthamii*] attracted our attention.

November 27

I saw here a noble fig-tree [probably *Ficus virens*] under the shade of which seemed to have been the camping place of the natives for the last century.

Its level bed was composed of a stiff bluish clay, without vegetation, mostly dry, and cracked by the heat of the sun; but its depressions were still moist, and treacherously boggy; in many parts of this extensive level, rose isolated patches, or larger island-like groves of Pandanus intermixed with drooping tea-trees and interwoven with Ipomaeas [possibly *Merremia gemella*] or long belts of drooping tea-trees, in the shade of which reaches of shallow water, surrounded by a rich sward of grasses of the most delicate verdure, had remained.

November 28

The country was most beautifully grassed: and a new species of Crinum [probably *Crinum angustifolium*] and several leguminous plants, diversified with their pretty blossoms the pleasing green of the flats and the forest.

November 29

The first part of the stage was more hilly, and intersected by a greater number of creeks, going down to west and north-west, than the latter part, which was a sandy, level forest of stringy-bark and Melaleuca gum [*Eucalyptus miniata*][314]. The little gooseberry-tree (Coniogeton arborescens, *D.C.*)[*Buchanania obovata*][315] the leguminous Ironbark, a smooth broad-leaved Terminalia [*Terminalia ferdinandiana*], Calythrix [probably *Calytrix exstipulata*][316], and the apple-gum [*Corymbia confertiflora*] were plentiful.

A grass, well known at the Hunter by its scent resembling that of crushed ants, was here scentless [possibly *Capillipedium parviflorum*]; a little plant, with large, white, tubular, sweet-scented flowers, grew sociably in the forest, and received the name of 'native primrose' [probably *Larsenaikia suffruticosa*][317]; a species of Commelyna, [probably *Commelina ensifolia*] and a prostrate malvaceous plant with red flowers [probably *Abelmoschus moschatus*][318], and a species of Oxystelma [possibly *Gymnanthera oblonga* or *Tylophora erecta*], contributed by their beauty and variety to render the country interesting.

---

[308] See also November 30, December 1, 14, 16, 17

[309] See also December 13

[310] See also November 26, 28, December 1, 2, 3, 9, 13, 14

[311] See also November 29, December 1, 9, 10, 17

[312] See also November 29 December 13, 17

[313] See also November 29

[314] See also December 17

[315] See also December 14, 17

[316] See also December 14

[317] See also December 1

[318] See also December 1

December 1

A species of Acacia [*Acacia* sp.][319] and stringy-bark saplings formed a thick underwood.

The open lawns were adorned by various plants, amongst which we noticed a species of Drosera, with white and red blossoms [*Drosera petiolaris*], a Mitrasacme [*Mitrasacme connata* or *M. nudicaulis*], a narrow-leaved Ruellia [*Brunoniella linearifolia*], the white primrose [*Larsenaikia suffruticosa*], the red prostrate malvaceous plant, a low shrubby Pleurandra [*Hibbertia sp.*], and an orchideous plant [*Dendrobium affine* or *Cymbidium canaliculatum*]—one of the few representatives of this family in the Australian tropics; the most interesting, however, was a prostrate Grevillea, with oblong smooth leaves, and with thyrsi of fine scarlet flowers; which I consider to be Grevillea Goodii, *R. Br.*[*Grevillea goodii*].

December 2

The natives were remarkably kind and attentive, and offered us the rind of the rose-coloured Eugenia apple, the cabbage of the Seaforthia palm [*Carpentaria acuminata* or *Hydriastele ramsayi*], a fruit which I did not know, and the nut-like swelling of the rhizoma of either a grass or a sedge [*Eleocharis dulcis*][320]. The last had a sweet taste, was very mealy and nourishing, and the best article of the food of the natives we had yet tasted. They called it 'Allamurr' (the natives of Port Essington, "Murnatt"), and were extremely fond of it. The plant grew in depressions of the plains, where the boys and young men were occupied the whole day in digging for it.

The men armed with a wommala, and with a bundle of goose spears, made of a strong reed [*Phragmites vallatoria*][321] or bamboo (?), gave up their time to hunting.

December 4

The Seaforthia palm [*Carpentaria acuminata*] raised it elegant crown far above the patches of vine brush which we passed at the river side of the ridges.

After a delay of two hours, we again started, and travelled in a due south direction towards some thick smoke rising between two steep and apparently isolated rocky hills: they were about four miles distant, and, when we arrived at their base, we enjoyed the pleasing sight of large lagoons, surrounded with mangrove myrtles (Stravadium) [*Barringtonia acutangula*], with Pandanus, and with a belt of reeds and Nelumbiums [*Nelumbo nucifera*][322].

December 6

We observed a great number of long conical fish and crab traps at the crossing place of the creek and in many of the tributary salt-water channels; they were made apparently of Flagellaria [*Flagellaria indica*].

We found a new Eugenia, a tree of rather stunted growth, with broad opposite leaves, and fruit of the size of an apple, of a delicate rose-colour [possibly *Syzygium eucalyptoides* subsp. *bleeseri*], and when ripe, a most delicious refreshment during a hot day. We had frequently met with this tree on sandstone ridges, and in sandy soils, but had never before found it in fruit.

December 7

The arborescent Vitex with ternate leaves [*Vitex glabrata*], which I had first met with at the Flying-Fox Creek of the Roper, was also observed here.

December 9

Mitrasacme elata [probably *Mitrasacme nudicaulis*] and all the other little plants I have before mentioned, were growing in the stringy-bark forest.

December 10

When the women returned at night, they did not bring 'Allamurr,' or, as it was here called, 'Murnatt,' but plenty of 'Imberbi,' the root of Convolvulus [possibly *Ipomoea gracilis* or *I. graminea*] which grow abundantly in the plain…

---

[319] See also December 17

[320] See also December 8

[321] See December 4

[322] See also December 5

December 13

For some miles, we followed a beaten foot-path, which skirted the large plain, and then entered the forest, which was composed of rusty-gum [probably *Corymbia bleeseri*], leguminous Ironbark, Cochlospermum gossypium and a small apocynaceous tree (Balfouria, Br.)[*Wrightia saligna*]; we crossed several salt-water creeks which went down to Van Diemen's Gulf.

Its water was so impregnated with the astringent properties of the gum-trees [*Eucalyptus* sp.]…

After pitching our tents, our guides went out, and returned with a small Iguana (Vergar), and with pods of the rose-coloured Sterculia [*Brachychiton megaphyllus*] which they roasted on the coals.

December 14

Scattered Pandanus and drooping tea-trees grew on their banks as far as the fresh water extended; when they were succeeded by the salt-water tea-tree [*Melaleuca acacioides*][323] and the mangrove, covering and fringing their beds, which enlarged into stiff plains, without vegetation, or into mangrove swamps. The latter were composed of Aegiceras [*Aegiceras corniculatum*], Bruguiera [probably *Bruguiera gymnorrhiza*], and Pemphis [*Pemphis acidula*].

They were all composed of a clayey ironstone, and clothed with patches of scrub, formed principally of Calythrix, and with a more open forest of Cypress pine [*Callitris intratropica*][324], white-gum [*Corymbia bella* or *C. grandifolia*], tea-trees, bloodwood [*Corymbia nesophila*] Livistona palms, Pandanus, with shrubby Terminalias [probably *Terminalia pterocarya*] and Coniogetons.

December 15

To ascertain this, I rode down the creek with Charley: it became more open; limited flats of sandy alluvium were clothed with the refreshing verdure of young grass, and with groves of Banksias [*Banksia dentata*][325] its hollows were fringed with large drooping tea-trees.

December 16

… on the sandy flats towards the hilly forest; where we also found a new tree, a species of Anacardium which the natives called 'Lugula;' it bore a red succulent fruit, formed by the enlargement of the stalk, with a greyish one-seeded nut outside, like Exocarpus [*Semecarpus australiensis*]. The fruit was extremely refreshing; the envelope, however, contained such an acrid juice that it ate into and discoloured my skin, and raised blisters wherever it touched it.

In the forest, we met with some few small Seaforthia [*Hydriastele ramsayi*][326] palms, the young shoots of which we obtained with great difficulty, not then knowing how easily the natives strip them of the surrounding leaves and leafstalks.

December 17

The forest was principally composed of stringy-bark, the leguminous Ironbark, Melaleuca-gum with underwood of Acacias, Coniogeton, Pachynemas [probably *Pachynema complanatum*][327] Pultenaeas [possibly *Jacksonia dilatata*] and Careya [*Planchonia careya*]. A tree very much resembling the real Ironbark (Eucalyptus resinifera) was observed at the Warvi [*Eucalyptus jensenii*]; but I expect it will be found entirely different.

---

[323] See also December 15

[324] See also December 17

[325] See also December 17

[326] See also December 17

[327] '*Pachynema complanatum*' is listed under an entry 'Plants of my Expedition' in Leichhardt's (1842–1847, p. 42) notebook.

Table 2. Species that have been assigned unambiguously to Leichhardt's references in the journal of the Port Essington Expedition with a high level of certainty, according to each geographic section.

Condamine: *Acacia harpophylla, Acacia melvillei, Acacia pendula, Acacia semilunata, Acacia triptera, Angophora floribunda, Angophora leiocarpa, Aotus subglauca, Brachychiton populneus* subsp. *populneus, Brachychiton rupestris, Brunonia australis, Bulbine alata, Calandrinia balonensis, Casuarina cristata, Citrus glauca, Corymbia citriodora* subsp. *variegata, Corymbia tessellaris, Eremophila mitchellii, Eryngium plantagineum, Eucalyptus coolabah, Eucalyptus crebra, Eucalyptus fibrosa* subsp. *nubila, Eucalyptus populnea, Euchiton sphaericus, Geijera parviflora, Goodenia grandiflora, Goodenia grandiflora, Grevillea striata, Hakea lorea, Hakea purparea, Hibiscus sturtii, Jacksonia scaparia, Leptospermum polygalifalium, Lysiana exacarpi* subsp. *tenuis, Lysicarpus angustifalius, Melaleuca bracteata, Neptunia gracilis, Owenia acidula, Persoonia sericea, Phragmites australis, Ranunculus meristus, Scaevola spinescens, Themeda triandra, Verbena gaudichaudii, Xanthorrhoea johnsonii, Zieria aspalathoides*

Dawson: *Acacia bidwillii, Acacia horpopylla, Acacia melvillei, Acacia stenophylla, Allacasuarina inophloia, Alphitonia excelsa, Angophora floribunda, Brachychiton rupestris, Bracteantha bracteantha, Cadellia pentastylis, Callistemon viminalis. Callitris glaucophylla, Capparis lasiantha, Capparis mitchellii, Casuarina cunninghamiana, Corymbia citriodara* subsp. *variegata, Carymbia tessellaris, Crinum flaccidum, Daucus glochidiatus, Dodonaea vestita, Dodonaea viscosa* subsp. *spatulata, Eremocitrus glauca, Eremaphila debilis, Eremaphila mitchellii, Eryngium plantagineum, Erythrina vespertilio, Eucalyptus coolabah, Eucalyptus crebra, Eucalyptus melanophlaia, Eucalyptus orgadophila, Eucalyptus populnea, Ficus coronata, Flindersia australis, Grevillea longistyla, Grevillea sessilis, Grewia latifolia, Imperata cylindrica, Jacksania scaparia, Leptospermum polygalifolium, Livistona nitida, Lophostemon suavealens, Bauhinia carronii, Macrazamia fearnsidei, Macrozamia moorei, Melaleuca trichostachya, Melia azedarach, Nymphoides crenata, Persoonia falcata, Persoonia subtilis, Petalastigma pubescens, Phragmites australis, Rhynchosia minima, Rubus parvifolius, Sonchus hydrophilus, Thysanatus tuberosus, Trichodesma zeylanicum, Verbena gaudichaudii, Xantharrhoea johnsonii, Xylomelum cunninghamianum*

Comet-Mackenzie: *Acacia excelsa, Acacia harpophylla, Acacia pendula, Acacia salicina, Acacia stenophylla, Arundinella nepalensis, Callitris glaucophylla, Calostemma luteum, Canavalia popuana, Capparis lasiantha, Capparis loranthifalia* var. *bancroftii, Capparis mitchellii, Cassia brewsteri, Casuarina cunninghamiana. Citrus glauca, Corymbia tessellaris, Cucumis melo, Dendrophthoe homoplastica, Enchylaena tomentosa, Eremophila maculata, Eremophila mitchellii, Eucalyptus caolabah, Eucalyptus melanophloia, Eucalyptus popalnea, Ficas oppasita, Flindersia dissosperma, Leptochloa digitata, Bauhinia carronii, Bauhinia hookeri, Melia azedarach, Muehlenbeckia florulenta, Nelumbo nucifera, Passiflara aurantia, Periscaria orientalis, Phragmites australis, Portulaca oleracea, Rhynchosia minima, Santalum lanceolatum, Sida sabspicata, Tribulus terrestris, Verbena gaudichaudii*

Peak Downs: *Acacia farnesiana, Acacia harpaphylla, Acacia pendula, Acacia rhadoxylon, Brunoniella australis, Casuarina cunninghamiana, Cissus opaca, Corymbia citriodora* subsp. *citriodora, Corymbia leichhardtii, Corymbia tessellaris, Crinum flaccidum, Diospyros humilis, Eremophila maculata, Eremophila mitchellii, Erythrina vespertilio, Eucalyptus coolabah, Eucalyptus crebra, Eucalyptus melanophloia, Eucalyptus platyphylla, Ficus apposita, Grevillea parallela, Heteropogon triticeus, Hypoxis arillacea, Lagenaria sicecaria, Larsenaikia ochreata, Livistona decora, Melaleuca nervosa, Ocimum tenuiflorum, Owenia acidula, Persoonia falcata, Petalostigma pubescens, Pleiogynium timorense, Portulaca oleracea, Scaevola spinescens, Trichodesma zeylanicum, Verbena macrostachya, Wrightia saligna, Xanthorrhoea johnsanii*

Suttor: *Acacia cambagei, Acacia harpophylla, Aeschynomene indica, Caldesia aligococca, Canavalia papuana, Cassia brewsteri, Casuarina cunninghamiana, Corymbia leichhardtii, Corymbia tessellaris, Cymbidium canaliculatum, Datura leichhardtii, Diplatia furcata, Dipteracanthus australasicus* subsp. *australasicus, Eremophila mitchellii, Eucalyptus camaldulensis, Eucalyptus coolabah, Grevillea glauca, Heteropogon triticeus, Livistona lanuginosa, Bauhinia carronii, Bauhinia hookeri, Melaleuca nervosa, Melaleuca tamariscina, Muehlenbeckia florulenta, Owenia acidula, Petalostigma banksii, Petalostigma pubescens, Phragmites australis, Planchonia careya, Sesbania cannabina*

Burdekin: *Abrus precatorius, Acacia bidwillii, Acacia galioides, Acacia harpophylla, Acacia shirleyi, Acacia victoriae, Alocasia brisbanensis, Alphitonia excelsa, Amyema miquelii, Brachychiton australis, Bursaria incana, Caldesia aligococca, Callisteman viminalis, Casuarina cunninghamiana, Celtis paniculata, Clerodendrum floribundum, Cordia dichatama, Corymbia leichhardtii, Corymbia peltata, Corymbia tessellaris, Dendrocnide photinophylla, Diplocyclos palmatus, Eremophila mitchellii, Erythrina vespertilio, Erythrophleum chlorostachys, Eucalyptus camaldulensis, Eucalyptus tetrodonta, Ficus apposita, Ficus racemosa, Grevillea parallela, Grevillea pteridifolia, Grevillea striata, Hakea arbarescens, Hakea larea, Lophostemon grandiflorus, Meloleuca bracteata, Melia azedarach, Manachoria cyanea, Phragmites australis, Pipturus argenteus, Planchania careya, Pleiogynium timorense, Schefflera actinophylla, Sesbania cannabina, Trichosanthes pentaphylla , Xanthorrhoea jahnsonii*

Lynd-Mitchell: *Acacia bidwillii, Adenanthera abrosperma, Barringtonia acatangula, Borania bowmanii, Callitris intratropica, Calytrix leptophylla, Canavalia papuana, Casuarina cunninghamiana, Cathormian umbellatum* subsp. *monilifarme, Cissus opaca, Cachlospermum gregorii, Corymbia confertiflara, Carypha utan, Diplatia grandibractea, Erythrophleum chlorastachys, Eucalyptus camaldulensis, Eucalyptus chartaboma, Eucalyptas shirleyi, Eucalyptus tetrodonta, Exocarpos latifolius, Ficus racemosa, Ficus rubiginasa, Gardenia vilhelmii, Grevillea dryandri. Grevillea mimasoides, Grevillea parallela, Grevillea pteridifolia, Grevillea striata, Hakea persiehana, Heteropogon triticeus, Bauhinia cunninghamii, Melaleuca viridiflora, Melia azedarach, Merremia hederacea, Nauclea orientalis, Petalostigma pubescens, Phragmites vallataria, Siphonodan pendulus, Terminalia platyphylla, Terminalia platyptera, Xanthorrhoea johnsanii, Xylamelum scottianum*

Eastern Gulf of Carpentaria: *Acacia bidwillii, Acacia farnesiana, Acacia sutherlandii, Asteramyrtus symphyocarpa, Atalaya hemiglauca, Barringtonia acutangula, Calycopeplus casuarinoides, Canavalia papaona, Casuarina cunninghamiana, Cathormion umbellatum* subsp. *moniliforme, Corymbia bella, Corymbia canfertiflora, Corymbia polycarpa, Cucumis melo, Erythrapleum chlorostachys, Eacalyptus camaldulensis, Eucalyptus pruinasa, Excoecaria parvifolia, Ficus oppasita, Gardenia vilhelmii, Grevillea dryandri, Grevillea mimosoides, Grevillea parallelo, Grevillea striata, Hakea arbarescens, Hakea larea, Heterapogon triticeus, Hibiscus tiliaceus, Livstana rigida, Baahinia cunninghamii, Melia adzederach, Merremia gemella, Nauclea orientalis, Nelumbo nucifera, Nymphoides crenata, Owenia reticulata, Pandanus aquaticus, Pandanus spiralis, Parinari nonda, Petalostigma pubescens, Terminalia canescens, Terminalia platyphylla, Terminalia platyptera, Thryptomene aligandra*

Western Gulf of Carpentaria: *Acacia wickhamii, Banksia dentata, Barringtonia acutangula, Brachychiton diversifolius, Brachychiton paradoxus, Callitris intratropica, Canavalia papuana, Casuarina cunninghamiana, Cathormion umbellatum, Corymbia bella, Corymbia confertiflora, Crotalaria cunninghamii, Cycas angulata, Erythrophleum chlorostachys, Eucalyptus camaldulensis, Eucalyptus miniata, Eucalyptus tetrodonta, Excoecaria parvifolia, Flagellaria indica, Grevillea mimosoides, Grevillea pteridifolia, Grevillea pungens, Grewia retusifolia, Haemodorum coccineum, Hibiscus tiliaceus, Hibiscus zonatus, Livistona inermis, Melaleuca acacioides, Melaleuca viridiflora, Melastoma malabathricum, Mucuna gigantea, Nauclea orientalis, Nymphoides crenata, Nymphoides indica, Pandanus aquaticus, Petalostigma pubescens, Philydrum lanuginosum, Syzygium suborbiculare, Terminalia canescens, Terminalia platyphylla, Themeda triandra*

Arnhem Land plateau: *Acacia valida, Allosyncarpia ternata, Banksia dentata, Bossiaea bossiaeoides, Buchanania obovata, Callitris intratropica, Capparis umbonata, Casuarina cunninghamiana, Cathormion umbellatum, Corymbia confertiflora, Corymbia* sp., *Crinum angustifolium, Elaeocarpus arnhemicus, Erythrophleum chlorostachys, Eucalyptus miniata, Eucalyptus phoenicea, Eucalyptus tetrodonta, Excoecaria parvifolia, Exocarpos latifolius, Ficus racemosa, Grevillea pteridifolia, Grevillea pungens, Grevillea rubicunda, Hakea arborescens, Hydriastele wendlandiana, Livistona inermis, Melaleuca viridiflora, Mucuna gigantea, Nauclea orientalis, Persoonia falcata, Petraeomyrtus punicea, Phragmites vallatoria, Planchonia careya, Syzygium suborbiculare, Terminalia platyphylla, Timonius timon, Trichodesma zeylanicum, Vitex glabrata*

Top End Lowlands: *Aegiceras corniculatum, Bambusa arnhemica, Banksia dentata, Barringtonia acutangula, Brachychiton megaphyllus, Brunoniella linearifolia, Buchanania obovata, Callitris intratropica, Carpentaria acuminata, Cochlospermum fraseri, Corymbia confertiflora, Corymbia nesophila, Drosera petiolaris, Eleocharis dulcis, Erythrophleum chlorostachys, Eucalyptus jensenii, Eucalyptus miniata, Eucalyptus tetrodonta, Flagellaria indica, Grevillea goodii, Hydriastele ramsayi, Kailarsenia suffruticosa, Livistona benthamii, Livistona humilis, Melaleuca acacioides, Nelumbo nucifera, Pandanus spiralis, Pemphis acidula, Phragmites vallatoria, Planchonia careya, Semecarpus australiensis, Syzygium eucalyptoides* subsp. *bleeseri, Syzygium suborbiculare, Terminalia ferdinandiana, Vitex glabrata, Wrightia saligna*

The record of plants and their distribution

A summary of the plants that can be unambiguously assigned to species from Leichhardt's journal of the Port Essington Expedition indicates a tally for the entire journey of 262 species (Table 2).

There are a few species that have not been relocated in the areas they were recorded by Leichhardt. Some may have become locally extinct e.g. *Trichosanthes pentaphylla* on the Burdekin River, but others undoubtedly await rediscovery, a notable possibility being *Sambucus gaudichaudiana* in the Expedition Range area (see December 9, 1844). J. Dowe recently relocated *Livistona decora* in the Carborough Range, after being alerted to the reference recorded by Leichhardt on March 5, 1845. Leichhardt described a stiff-leaved form of *Ipomoea* from the Gulf of Carpentaria on August 6, 1845 that may correspond to specimens of an undescribed species of limited distribution (R. Johnson pers. comm.)

Detailed interpretation of the impact of European settlement is difficult using the Port Essington Expedition journal as a baseline. Leichhardt provides relatively few clues about the abundance of the taxa that he observed and there has been no systematic botanical survey of Leichhardt's route to generate modern data on the distribution of the plants that Leichhardt observed. The presence of contemporary Herbarium collections certainly suggests that the majority of the plant species described by Leichhardt could still be found in the general locality of Leichhardt's records after 160 years of dramatic landscape change. This is perhaps not surprising in view of the fact that most of the species described in the journal are long-lived woody species. However, some of these tree and shrub species have undoubtedly suffered major decline. The brigalow (*Acacia harpophylla*) scrubs have been cleared to less than 10% of their former area (Wilson *et al.* 2002), but the species remains relatively common as regrowth, and roadside remnants are widely scattered throughout its former vast range. Within the brigalow and associated vegetation some elements have become rare with clearing. The distribution of Ooline (*Cadellia pentastylis*) was always patchy but it occurs on fertile soils in the Brigalow Belt region and its populations have been greatly reduced, including those in the Taroom district where Leichhardt recorded the tree on November 17, 1844. Leichhardt's sighting of a ground orchid in the genus *Prasophyllum* on the basaltic grassland plains of the Darling Downs (October 3, 1844) is notable. This area has been the subject of vegetation survey over recent years (including Fensham 1998), and no ground orchids were found in that habitat, suggesting that they are now exceedingly rare or locally extinct.

In Australia, a common definition of an indigenous plant is one that was present before European settlement. Following that definition, it seems highly likely that any plant recorded by Leichhardt beyond areas of settlement should be deemed an indigenous species. The following species have previously been considered exotic species by some authors, but on the evidence presented here should therefore be recognised as indigenous: *Acacia farnesiana, Aeschynomene indica, Cucumis melo, Datura leichhardtii, Ipomoea nil, Lagenaria sicecaria, Melochia pyramidata, Ocimum tenuiflorum, Portulaca oleracea, Salsola kali* and *Verbena gaudichaudii.*

Leichhardt's botanical contribution to Australia

During his relatively brief time in Australia, Leichhardt collected thousands of good-quality plant specimens. The early specimens were collected between February 1842 and September 1844, at various places between Sydney and Moreton Bay. While this collection undoubtedly included 'new' species, most specimens would have been of known species, and hence not so eagerly sought by European botanists. The Port Essington Expedition, however, traversed country remote from European settlement and many of the species Leichhardt collected would have been new to science. If the plant collection from the Port Essington Expedition had survived and new species described, it would have been comparable with the north Australian collections of Brown in the Investigator in 1801–02 and the later collections of Mueller made on the Gregory expedition in 1858, and Leichhardt's name would have been much more widely recognised in botanical circles.

Of the plant species that can be unambiguously determined from the Port Essington Expedition journal, 120–150 were completely unknown at the time, and would have represented the first botanical specimens. These include, for example, *Lysicarpus angustifolius, Cadellia pentastylis, Grevillea longistyla, Acacia rhodoxylon, Petraeomyrtus punicea* and *Hydriastele ramsayi*. The botanical references in the journal are biased towards trees as they formed obvious landmarks that summarised the nature of the country that was being traversed. It was obviously impractical for Leichhardt to mention the plants of lesser stature in his journal, as they would be of little interest to most readers, and it would have increased the amount of text perhaps two-fold. However, Leichhardt indicated that his dried plant collection (of 4–5000 specimens by the time the party reached the Roper River) included many of 'the less conspicuous' species. Some collections of these less conspicuous herbaceous plants, not mentioned in the journal, have survived e.g. *Arthrostylis aphylla* and *Mitrasacme elata* (Table 1). To achieve 4–5000 specimens between Jimbour and Roper River, Leichhardt must have collected an average of 11–13 specimens per day. This would be a reasonable effort for a botanist who had no other duties on the expedition, but is remarkable when one considers Leichhardt's myriad other chores and duties.

The final major collecting effort by Leichhardt was during the aborted Swan River expedition of 1846–47. This expedition followed almost the same route as the Port Essington Expedition, but only as far as the Peak Range (Fig. 1). Most of the collections from this journey survive, with many specimens in Australian herbaria. The journey was disastrous in many respects. The party was beset by debilitating sickness, marauding insects, and spent much of their time chasing errant stock animals in wet and muddy conditions; the morale of the party and Leichhardt's leadership were undermined by nasty infighting (Sprod 1989). It is not surprising that Leichhardt described the specimens from that expedition as 'very much injured' (Aurousseau 1968, p. 976).

Leichhardt had great botanical talents, and was familiar with many Australian genera. The Sydney area was an ideal place to learn the Australian flora, as it was the only part of the continent where the flora was relatively well known and has a broad spectrum of genera representing the eastern areas of the continent at least. His journeys to Moreton Bay introduced him to some of the tropical families and genera, and this held him in good stead during the Port Essington Expediton. Throughout the journal, his identifications are for the most part either close to the mark or correct for the day. There are a few glaring misidentifications such as the tree he clearly described as *Pleiogynium timorense* (Anacardiaceae), but considered it 'probably Ebenaceous' i.e. of the family Ebenaceae. He failed to discriminate some eucalypt species he saw during the expedition. For example, he lumped several well-marked species, such as the box-barked *Eucalyptus pruinosa* as 'silver-leaved ironbark', and a range of bark types as 'rusty gum'. However, concepts of eucalypt taxonomy were only beginning to emerge at the time. It is interesting to note that Leichhardt used all of the current terms for bark groupings in eucalypts (gum, bloodwood, stringybark, ironbark and box) in his journal. He had almost certainly picked up the terms from squatters and timber-getters he had met in his travels where they had become vernacular in the early decades of European settlement. The Port Essington Expedition journal may well represent the first widely read published account of these names and was almost certainly influential in the widespread adoption of this scheme for describing eucalypts.

Leichhardt had a generally enlightened and sympathetic attitude to aboriginal people. His journal has a plethora of carefully observed ethnobotanical observations. These original documentations of traditional plant use could be the subject of another interesting analysis and publication.

Leichhardt's background in the natural sciences distinguished him from the other major explorers of his era and his desire to describe and understand the natural world was the primary motive for his explorations; even if he was probably somewhat less humble than this passage in a letter would have us suppose:

...whatever I have done has never been for honour. I have worked for the sake of science, and for nothing else; and I shall continue to do so even if not a soul in the world pays any attention to me. (Aurousseau 1968, p. 993–994)

There is little doubt that Leichhardt had the potential to make some outstanding published contributions to science. However, Leichhardt died a young man in his mid-30s, and during his short life, obsessive ambitions for exploration overshadowed almost everything else. Leichhardt died during his third major expedition, an infamous and ill-fated attempt to cross the continent from east to west (Lewis 2006). His short life did not allow him to turn his prodigious talent and intellect to product in terms of formal botanical publication, despite clearly stated intentions in that direction:

But let me only get back from Swan River and I shall call on many people and then we will both go together to England and gather like bussy bees all the knowledge which might be available for New South Wales; I want very much to coin my 'impressions de voyage' into exact science. (Aurousseau 1968, p. 888–9).

One of his few publications was a broad geographical overview of the landscapes observed along the route of the Port Essington Expedition (Leichhardt 1847b), a truly remarkable document prescient of the land systems studies that commenced with Christian and Stewart (1952) and biogeographic regions (e.g. Thackway and Cresswell 1995). Despite his premature death the reputation of Ludwig Leichhardt as a great natural scientist should be affirmed.

Acknowledgements

Many people have provided expert local knowledge that has greatly improved our ability to more accurately identify Leichhardt's botany. Invaluable advice on the likely identity of many species was provided by Gary Alsemgeest, Kym Brennan, Ian Cowie, Russell Cumming, Ian Fox, Gordon Guymer, John Heelan, Betsy Jackes, Laurie Jessup, Bob Johnson, Grace Lithgow, Les Pedley and Ian Telford. We are very grateful to Clemency Fisher for allowing us to use her unpublished transcript of John Gilbert's dairy, and to the University of Adelaide Library, Electronic Texts Collection for providing the full text of Leichhardt's journal freely on the worldwide web. Alex George is thanked for searching for Leichhardt specimens in British herbaria. Wil Smith prepared the map.

References

Aurousseau, M. (1968) *The letters of F. W. Ludwig Leichhardt, Volumes II & III*. (Cambridge University Press: Cambridge).

Baker, R.M. & Barker W.R. (1990) Botanical contributions overlooked: the role and recognition of collectors, horticulturists, explorers and others in the early documentation of the Australian flora. In Short, P.S. (Ed.) *History of systematic botany in Australasia*, pp. 37–85. (Australian Systematic Botany Society: South Yarra).

Bell, J. (2004) (Ed.). *From Jimba to Dried beef Creek: Leichhardt's travels in the Chinchilla District 1844–1848*. (Chinchilla Shire Library: Chinchilla).

Brown, R. (1810) *Prodromus florae Novae Hollandiae et insulae Van Diemen...*(J. Johnson and Co: London).

Bunce, D. (1979) *Travels with Dr Leichhardt*. (Oxford University Press: Melbourne).

Candolle, A.P. de *et al.* (1823–1873) *Prodromus systematis naturalis regni vegetabilis*. 17 Volumes (Treutell & Würtz: Paris).

Chisholm, A.H. (1955) *Strange new world: the adventures of John Gilbert and Ludwig Leichhardt*. (Angus & Robertson: Sydney).

Christian, C.S. & Stewart, G.A. (1952) General report on survey of Katherine-Darwin regions, 1946. *CSIRO Australian Land Research Series 1*.

Dowe, J.L. (2005) Ludwig Leichhardt's Australian plant collections, 1842–1847. *Austrobaileya* 7: 151–163.

Endlicher, S.F.L. (1836–1841) *Genera Plantarum secundum ordines naturales disposita*, parts 1–18. (Fr. Beck: Vienna).

Fensham, R.J. (1998) The grassy vegetation of the Darling Downs, south-eastern Queensland, Australia. Floristics and grazing effects. *Biological Conservation* 84: 301–310.

Gilbert, J. (1844–1845) Diary. Leichhardt's Expedition to Port Essington, 1844–45. Typed transcript, Mitchell Library, State Library of New South Wales, Sydney.

Hodgson, P. (1846) *Reminiscences of Australia : with hints on the squatter's life*. (W.N. Wright: London).

Jackes, B.R. (1990) Retracing the botanical steps of Leichhardt and Gilbert in June 1845. In P.S. Short (Ed.) *History of systematic botany in Australasia*, pp. 165–169. (Australian Systematic Botany Society: South Yarra).

Leichhardt, L. (1842–1847) Unpublished notebook. Mitchell library ML C154, Microfilm MAV/FM4/3092.

Leichhardt, L. (1844–45) Field book, 1844–45, used on the exploration journey from Moreton Bay to Port Essington. Original held by the Mitchell Library, State Library of New South Wales at ML C158.

Leichhardt, L. (1847a) *Journal of an overland expedition in Australia from Moreton Bay to Port Essington*. (T. & W. Boone: London).

Leichhardt, L. (1847b) Lectures on the geology, botany, natural history, and capabilities of the country between Moreton Bay and Port Essington. *Tasmanian Journal of Natural Science* 3: 81–113.

Lewis, D. (2006) The fate of Leichhardt. *Historical Records of Australian Science* 17: 1–30.

McLaren, G. (1993) Retracing Leichhardt. Field notes Vol. 1 and Vol. 2. The development of the traditions of scientific research and bushmanship in 19th century Australia, with special reference to the contributions of Ludwig Leichhardt (1994). PhD thesis. Curtin University of Technology, Perth.

McLaren, G. (1994) *Beyond Leichhardt. Bushcraft and the exploration of Australia*. (Fremantle Arts Centre Press: South Fremantle).

Roderick, C. (1988) *Leichhardt the dauntless explorer*. (Angus & Robertson: North Ryde).

Sprod, D. (1989) *Proud Intrepid Heart. Leichhardt's first attempt to the Swan River*. (Blubber Head Press: Hobart).

Telford, I.R. (1982) Cucurbitaceae *In* Flora of Australia. Volume 8 Lechythidales to Batales. (Australian Government Publishing Service: Canberra.).

Thackway, R. & Creswell, I. D. (1995) An Interim Biogeographic Regionalisation for Australia: A Framework for Setting Priorities in the National Reserves System Cooperative Program, Version 4.0. (Australian Nature Conservation Agency: Canberra).

Webster, E.M. (1986) *An explorer at rest. Ludwig Leichhardt at Port Essington and on the homeward voyage 1845–1846*. (Melbourne University Press: Melbourne).

Wilson, B.A., Neldner, V.J. & Accad, A. (2002) The extent and status of remnant vegetation in Queensland and its implications for statewide vegetation management and legislation. *Rangeland Journal* 24: 6–35.

Manuscript accepted 14 March 2006

Leaf, tree and soil properties in a *Eucalyptus saligna* forest exhibiting canopy decline

Christine Stone[A] *and Jack A. Simpson*[B]

[A]New South Wales Department of Primary Industries Science and Research, PO Box 100, Beecroft, NSW 2119, AUSTRALIA.
[B]15 Sprent Street, Narrabundah, ACT, 2604, AUSTRALIA. [A]Corresponding author email: christines@sf.nsw.gov.au

Abstract: The extent of eucalypt decline in moist coastal forests of south-eastern Australia is increasing with resultant losses in biodiversity and productivity. This survey aimed to identify factors associated with the decline of *Eucalyptus saligna* (Sydney Blue Gum) in Cumberland State Forest, a moist sclerophyll forest within urban Sydney. *Eucalyptus saligna* was the dominant overstorey species in six 20 m radius plots, which differed in floristic composition, structure and crown condition. One plot was colonised by bell miners (*Manorina melanophrys*). A range of leaf, tree and plot scale parameters were assessed including insect damage and free amino acid content, visual crown condition, floristics and soil chemistry. The plot permanently colonised by bell miners also had *Eucalyptus saligna* trees in the poorest condition. Both the weed *Lantana camara* and the soil pathogen *Phytophthora cinnamomi* were present in some of the plots but neither was strongly consistent with the severity of crown decline. There were, however, significant correlations among the foliar traits of insect damage, free amino acid content and relative chlorophyll content. Free amino acid content differed significantly between leaf age cohorts. Plots differed notably in topsoil organic matter and soil nitrogen, but the plot with the poorest visual crown condition score had intermediate mean values for both soil properties within the ranges presented by the six plots. Overall, crown condition score was weakly negatively correlated with topsoil organic carbon and total nitrogen content. The unhealthiest plot also had the highest density of shrubby understorey. Site factors that could influence both the quantity and quality of foliage (e.g. free amino acid content) in eucalypt crowns, and hence the population dynamics of herbivorous insects and bell miners, are discussed in relation to *Eucalyptus saligna* crown decline.

Cunninghamia (2006) 9(4): 507–520

Introduction

Stand decline has been observed in Australian native forests and woodlands for many decades (e.g. Edgar et al. 1976; Landsberg & Wylie 1988). Awareness of the extent of eucalypt canopy decline in Australian native forests has increased considerably over recent years (e.g. Stone 1999, Old 2000, Jurskis 2005). Past studies have attempted to identify the causal agents or processes associated with eucalypt decline in native forests but with mixed success (Podger et al. 1980, Old 2000). Numerous factors, both biological and environmental, have been related to dieback but on their own usually do not account for all the observed variation associated with a particular decline syndrome. For example, both West (1979) and Podger (1981) presented strong circumstantial evidence of drought being a principal causal factor for stand death in Tasmanian eucalypt forests referred to as 'regrowth dieback'. However, drought-affected trees in these forests were predisposed to defoliation by paropsine beetles and to root rot caused by *Armillaria* spp. (Kile 1974, 1980). In another series of Tasmanian studies (e.g. Ellis 1985; Ellis & Pennington 1989) the severity of the eucalypt dieback in high altitude *Eucalyptus delegatensis* forests was proposed to be related to the development of successional rainforest in the absence of fire.

There is currently debate about the causal factors of another form of eucalypt decline 'Bellminer associated dieback' (Wardell-Johnson et al. 2005). Eucalypt stands colonised by bell miners (*Manorina melanophrys*) often exhibit symptoms of crown decline (e.g. Clarke & Schedvin 1999; Jurskis & Turner 2002; Stone 2005). Bell miners are insectivorous, territorial birds that live in large colonies covering an area of several hectares (Clarke & Fitz-Gerald 1994). This eucalypt decline occurs most commonly in moist coastal forests, extending from southern Victoria to southern Queensland. While the actual extent of this dieback is unknown, numerous observations and regional surveys indicate that it is spreading (e.g. Stone et al. 1995; Jurskis 2005; Wardell-Johnson et al. 2005). Many thousands of hectares in the Northern Rivers and Upper North Coast regions of NSW have been identified as being affected by Bell miner associated dieback resulting in significant losses in biodiversity and productivity (Bell miner Associated Dieback Working Group, unpublished data, NSW Department of Environment). Colonisation by bell miners correlates with high densities of leaf damaging psyllids in eucalypt tree crowns (Loyn et al. 1983; Stone 1996; Clarke & Schedvin 1999). If bell miners are removed from a site, it is invaded by other insectivorous birds, and psyllid numbers decline, often resulting in tree crown recovery (Loyn et al. 1983). A reduction in psyllid numbers, however, does not always lead to recovery of stand health (Clarke & Schedvin 1999). Eucalypts constantly replacing damaged leaf tissue deplete their reserves, are weakened and become more susceptible to secondary insect pests such as stem borers and fungal pathogens (e.g. Old et al. 1990). A stand of eucalypts colonised by bell miners for approximately 20 years did not recover upon their removal (Clarke & Schedvin 1999).

Jurskis and Turner (2002) have proposed a generic model of eucalypt dieback that includes stands colonised by bell miners. A central theme of their model is that recent changes in land management practices, particularly the exclusion of low intensity fire in forests and woodlands, has favoured the development of dense mesic understoreys. This results in increased rates of litter fall which changes the soil conditions and inhibits tree roots and mycorrhizae. They cite a series of studies that support their claim that these factors are likely to promote unhealthy roots, nitrification, insect damage to leaves and eucalypt dieback. Stone (1999), studying crown decline of *Eucalyptus saligna* colonised by bell miners, proposed that success and persistence of a bell miner colony may be related to site factors including the maintenance of high insect numbers in tree crowns as a food source, a dense understorey providing nesting sites, available drinking water, and a defendable territory. Processes that maintain these site factors therefore contribute directly to the success of the bell miner colonies, and hence the risk of persistent crown defoliation by larger populations of herbivorous insects.

Discussions on eucalypt forest decline have elements in common, but often lack consensus in the identification of factors that initiate the decline process. There may be several reasons for this apparent lack of consensus. Most studies on eucalypt decline (or dieback) have only considered some of the possible associated factors. This precludes quantitative syntheses such as meta-analyses of published studies, and limits reviews to narrative summaries (Bennett & Adams 2004). The majority of published studies have not been established as replicated field experiments with manipulated treatments that can be analysed to establish cause-effect relationships (Schreuder & Thomas 1991). Also native eucalypt forests span a large number of vegetation types (e.g. Forestry Commission of NSW 1989), varying considerably in species composition and structure and are inherently complex multi-tropic ecosystems that function across a range of temporal, spatial and organisational scales. Most published studies have not attempted to examine issues of physical and functional scale and how they inter-relate (e.g. leaf, crown, stand, landscape scales). The complex, yet finely balanced nature of native forests, and the differing approaches of investigation have contributed to a diversity of opinions and lack of consistent statistical evidence.

This study was a preliminary survey of some factors that have been implicated in Bell miner associated dieback, with the results to be used to design future studies in identifying cause and effect relationships across a range of scales. Six 20 m radius plots in a small moist sclerophyll forest were selected (Fig. 1) with the criteria that the dominant overstorey species was *Eucalyptus saligna*, but otherwise they differed in terms of floristic composition, structure and crown condition (Figs. 2A – F, Table 1). Only one of the six plots was colonised by bell miners. Although this survey lacked appropriate replication to enable statistical comparisons between plots colonised by bell miners and non-colonised plots, it was possible to address the following questions: i) Is there an association between crown condition and plot vegetation?; ii) Does the incidence of the fungal pathogens *Armillaria luteobubalina* and *Phytophthora cinnamomi* differ between plots?; iii) Is there an association between crown condition and soil chemical properties?; iv) Does the suite of foliar insects on *Eucalyptus saligna* foliage differ between plots? and v) What correlations exist among a range of physical and chemical leaf traits measured from *Eucalyptus saligna* foliage sampled from each plot?

Methods

Study area and plot assessment

The study site was Cumberland State Forest (S.F.) (33°47'S, 150°58'E), Sydney, New South Wales (Fig. 1). The site consists of 39 ha of intensively managed regrowth forest

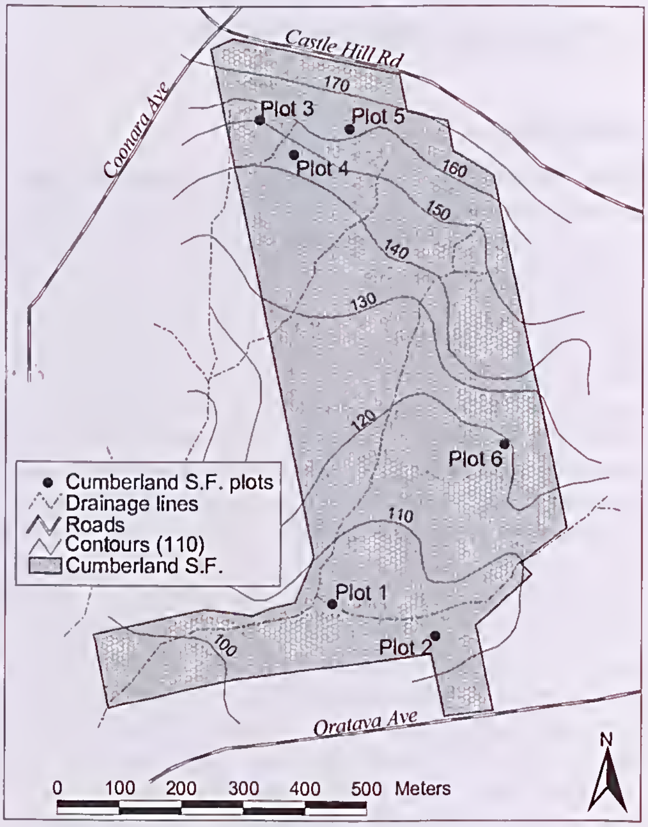


Fig. 1 Location of the six plots in Cumberland State Forest, Sydney.

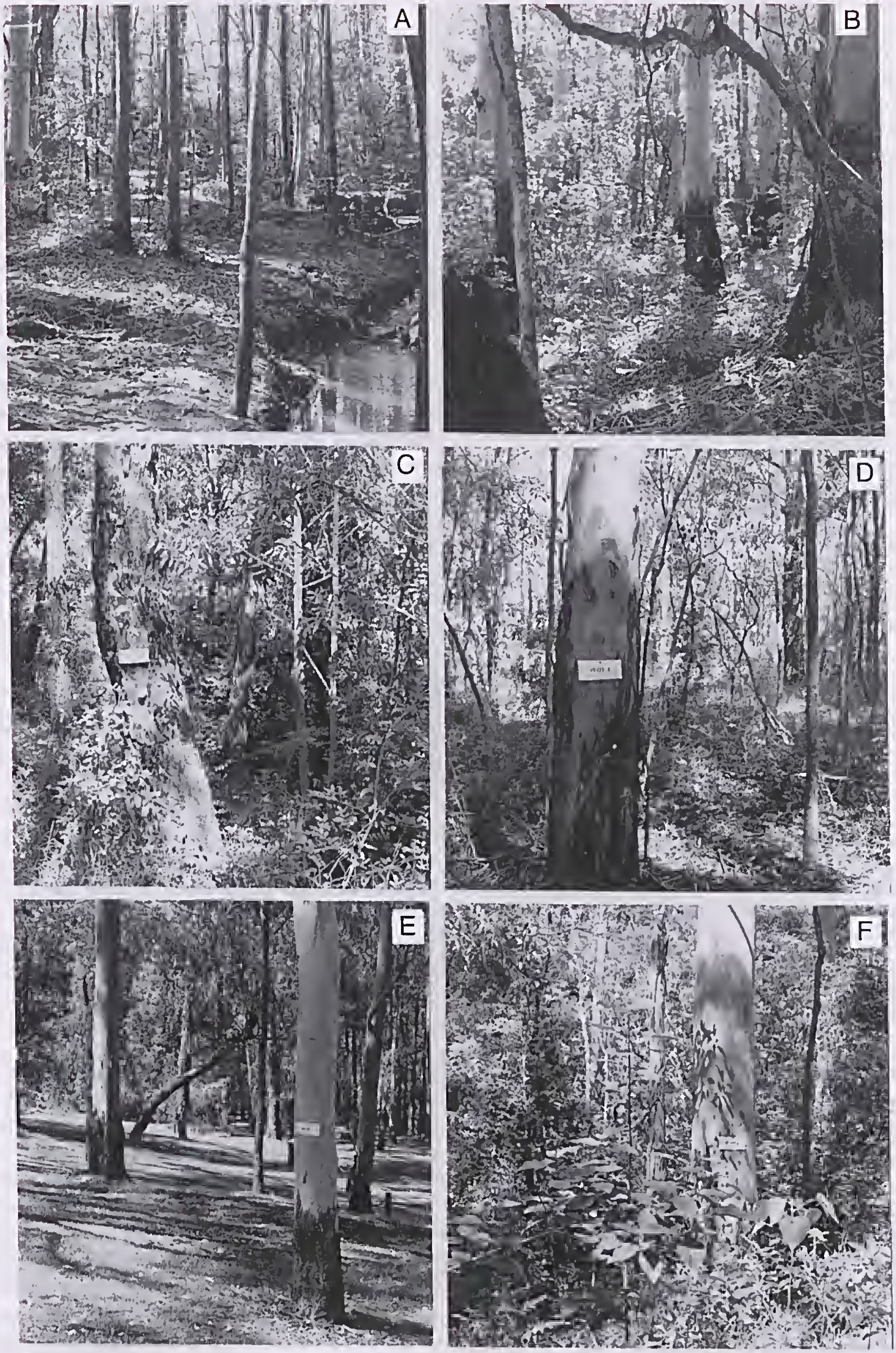


Fig. 2. Photographs illustrating the type of understorey present in each of the six plots in Cumberland State Forest: (**A**) plot 1, the creek plot; (**B**) plot 2, the mid slope plot; (**C**) plot 3, the bell miner plot; (**D**) plot 4, plot adjacent to the bell miner colony; (**E**) plot 5, the picnic area plot; (**F**) plot6, the bird counts plot.

surrounded by suburban development and is used principally for recreation. In the early 1900s part of Cumberland S.F. was cleared for fruit tree orchards, but in the 1930s areas were allowed to regenerate or were replanted with eucalypts. Cumberland S.F. receives an average annual rainfall of approximately 1100 mm and moderate daily temperatures (January mean max. 29°C, min. 16°C; July mean max. 16°C, min. 5°C) (Forestry Commission of NSW 1984). Monthly rainfall records from 1970 to 2003 for Cumberland S.F. were used to calculate White's Moisture Stress Index (White 1986). Standard normal deviates of their long-term means (33 years) were calculated for the periods November to February and May to August.

Six plots, approximately 20 m radius in size were located in mixed-age, moist stands within Cumberland S.F. In the northern half of Cumberland S.F. the geology is Wianamatta group Ashfield Shale. Soils derived from this Shale are deep, red, podsolic soils of clay loam texture with heavy clay layers in the B horizons (Forestry Commission of NSW 1984). Plots 3, 4, 5 and 6 (Fig. 1) were located on this soil. The soils in the southern half are derived from a combination of Hawkesbury Sandstone and Ashfield Shale parent materials, the latter washed down from higher shale areas. They are yellow podsolic soils with a sandy loam texture still retaining reasonable structure (Forestry Commission of NSW 1984). Plots 1 and 2 were located on this soil (Fig. 1). The six plots were selected so as to represent a range of floristic composition and structures present in the forest (Figs. 2A–F). A common factor for all the plots was the presence of mature trees of *Eucalyptus saligna*. Other tree species present in the overstorey included *Eucalyptus pilularis*, *Eucalyptus paniculata* and non-eucalypt species such as *Pittosporum undulatum* and *Glochidion ferdinandi*. The understorey varied considerably because of manual weed control and control burning, and ranged from grass (*Microlaena stipoides*) that was regularly mowed, to dense mesic shrubs that included the exotic weeds *Lantana camara* and *Ligustrum* spp. (Table 1). The structure of the plots was further characterised by stem density (stems per ha) and mean stem diameter per plot. Small sections of the forest had been treated with hazard reduction burns in 1991, 1993 or 1994. Plots 3 and 6 were burnt in 1993 and plot 1 in 1994. Remnant earthworks very close to plot 3 were from a road built in 1987 and subsequently abandoned.

Bell miner colonies have been recorded in Cumberland S.F. for approximately 30 years and movements between locations within the forest have been observed. Some formerly densely populated areas, now no longer support bell miners. More recently bell miners have tended to remain in proximity to a large dam on the northwestern boundary of the forest (Ian Johnson, member of the Cumberland Bird Observers Club). Some of the remnant Sydney blue gum forest in the surrounding suburbs also supports bell miner colonies but these habitats are declining due to clearance for housing.

Structure and crown measurements

Within each of the six plots, five similar-sized, mature *Eucalyptus saligna* trees were randomly selected and labeled for assessment and foliage sampling. At the time of foliage assessment (May 2002), tree heights, diameters (over bark at breast height) and diameter increments (20 months after the initial measurement) were measured. Plot 3 was the only plot permanently colonised by bell miners. A further five *Eucalyptus saligna* trees per plot were selected in the two plots situated close to plot 3 (neither of which were colonised permanently by bell miners) and differing from one another in understorey composition (Figs. 1, 2D & 2E; Table 1). The remaining 3 plots (plot 1, plot 2 & plot 6) were located at least 500 m south of the northern cluster of 3 plots (Fig. 1). The crown condition of each of the five labelled *Eucalyptus saligna* per plot was assessed using the visual crown scoring system for eucalypts (in Stone et al. 2003–Appendix 2). To provide a relative comparison of bell miner numbers between plots, four ten-minute bird counts were undertaken at the centre of each plot during Spring 2001; Autumn 2002 and Spring 2003 using the 10 m concentric circle technique (Shields 1990). Data were only accepted to the 30 m radius circle.

Pathogen sampling

Four soil samples per tree per plot were tested for the soil-borne fungal pathogen *Phytophthora cinnamomi*. The presence of *Phytophthora cinnamomi* was determined in the laboratory by baiting water suspensions of each soil sample with highly susceptible lupin seedlings (Chee & Newhook 1965). Searches for basidiomes of *Armillaria luteobubalina*, which is known to occur in Cumberland S.F. (J. Simpson, unpublished data) were made of each plot in autumn and winter in 2002 and 2003. Stumps and the butts of any dead trees in each plot were examined for the characteristic mycelial fans of *Armillaria luteobubalina*.

Soil sampling

Topsoil samples were also obtained from each plot. After brushing away the surface litter a hand-held auger was used to obtain four volumetric samples, 15 cm deep and located 2 m from the base of each labelled *E. saligna*, at the cardinal points. The samples from near each tree were then bulked and mixed well, before a 500 gm sub-sample was placed, within 30 minutes and numbered of sampling, into a drying oven for 48 hours at 40°C. After air drying, the thirty soil samples were sent to the Victorian State Chemistry Laboratory for chemical analysis using standard procedures (T. Ives, Victorian Dept of Natural Resources & Environment, Werribee, *pers. comm.*; Rayment & Higginson 1992). The chemical properties assayed are listed in Table 4.

Table 1. Native and exotic plant species recorded in the six plots in Cumberland State Forest

	Ground covers	Shrubs	Trees	Exotics
Plot 1	*Adiantum aethiopicum*	*Acmena* sp.	*Brachychiton* sp.	*Ligustrum lucidum*
	Blechnum cartilagineum	*Clerodendrum tomentosum*	*Eucalyptus saligna*	*Ligustrum sinense*
	Calochlaena dubia	*Cordyline stricta*	*Eucalyptus pilularis*	*Rubus fruticosus*
	Clematis aristata	*Lomandra* sp.	*Ficus coronata*	
	Eustrephus latifolius	*Morinda jasminoides*	*Glochidion ferdinandi*	(exotics = 5% abundance)
	Hypolepis muelleri	*Pittosporum revolutum*	*Pittosporum undulatum*	
	Lomandra mutiflora	*Platycerium bifurcatum*	*Syncarpia glomulifera*	
	Microlaena stipoides			
	Pandorea pandorana			
Plot 2	*Adiantum aethiopicum*	*Pittosporum revolutum*	*Eucalyptus saligna*	*Ligustrum lucidum*
	Blechnum cartilagineum	*Pittosporum undulatum*	*Eucalyptus pilularis*	*Ligustrum sinense*
	Clematis aristata	*Polyscias sambucifolia*	*Ficus coronata*	*Ochna serrulata*
	Dianella sp.		*Glochidion ferdinandi*	*Olea europaea*
	Dichondra repens		*Pittosporum undulatum*	*Protasparagus aethiopicus*
	Morinda jasminoides			*Tradescantia albiflora*
	Oplismenus aemulus			
	Pandorea pandorana			(exotics = 25% abundance)
Plot 3	*Cayratia clematidea*	*Clerodendrum tomentosum*	*Acacia parramattensis*	*Asparagus asparagoides*
	Cissus sp.	*Leucopogon juniperinus*	*Brachychiton* sp.	*Lantana camara*
	Dianella sp.	*Omalanthus populifolius*	*Eucalyptus paniculata*	*Ligustrum lucidum*
	Entolasia stricta	*Ozothamnus diosmifolius*	*Eucalyptus saligna*	*Ligustrum sinense*
	Lomandra sp.	*Pittosporum revolutum*	*Glochidion ferdinandi*	*Rubus fruticosus*
	Microlaena stipoides	*Trema aspera*	*Pittosporum undulatum*	*Solanum mauritianum*
	Morinda jasminoides			
	Plectranthus parviflorus			(exotics = 40% abundance)
Plot 4	*Adiantum aethiopicum*	*Pittosporum revolutum*	*Eucalyptus pilularis*	*Asparagus asparagoides*
	Clematis aristata		*Eucalyptus punctata*	*Ehrharta erecta*
	Echinopogon ovatus		*Eucalyptus saligna*	*Lantana camara*
	Eustrephus latifolius		*Pittosporum undulatum*	*Nephrolepis cordifolia*
	Lomandra longifolia			*Protoasparagus aethiopicus*
	Pandorea pandorana			*Rubus fruticosus*
	Pteridium esculentum			*Solanum mauritianum*
				(exotics = 15% abundance)
Plot 5	*Microlena stipoides*	*Acmena smithii*	*Acacia* sp.	*Cynodon dactylon*
			Eucalyptus pilularis	*Ehrharta erecta*
			Eucalyptus saligna	*Pennisetum clandestinum*
				(exotics = 80% abundance)
Plot 6	*Adiantum aethiopicum*	*Breynia oblongifolia*	*Alphitonia excelsa*	*Araujia sericifolia*
	Clematis glycinoides	*Omalanthus populifolius*	*Angophora costata*	*Asparagus asparagoides*
	Commelina cyanea	*Pittosporum revolutum*	*Eucalyptus pilularis*	*Lantana camara*
	Dichondra repens		*Eucalyptus saligna*	*Ligustrum sinense*
	Hypolepis muelleri		*Pittosporum undulatum*	*Ochna serrulata*
	Lomandra longifolia			*Protoasparagus aethiopicus*
	Pteridium esculentum			*Rubus fruticosus*
				Sonchus oleraceus
				(exotics = 25% abundance)

Leaf assessments

In May 2002, two upper crown branches were randomly selected from each tree and brought down with a pole-mounted slingshot (Big Shot: Jameson Corporation, Clover, South Carolina, USA). The labelled branches were taken immediately to a laboratory within Cumberland S.F. for leaf assessment. Three distinct leaf age cohorts, described as young, mature and old, were identified. The dominant leaf age cohort was the mature leaf age class, being fully expanded and initiated in the current season. The assessments of leaves from this leaf age cohort were used for comparisons of all the morphological, damage and physiological leaf traits except for free amino acid content in which the young leaf age cohort was also assayed. All measurements were based on a random sample of 20 mature leaves per branch ($n = 200$ per plot). A total of 556 young leaves were assayed for free amino acid content.

Initially, a measure of photosynthetic capacity was obtained by measurements of F_v/F_m, the ratio of variable fluorescence to maximum chlorophyll fluorescence, using a portable chlorophyll fluorometer (Fluorescence Induction Monitor 1500: ADC BioScientific Ltd, UK). One leaf clip was applied randomly on the leaves for 15-min dark adaptation while still attached to the branches that were standing upright in buckets of water. A SPAD chlorophyll meter (model 502, Minolta Co., Ltd, Tokyo, Japan) was used to obtain a unitless relative measure of chlorophyll concentration (an index from 0 to 1.0) from the same leaves used for the Fv/Fm measurements (Stone et al. 2005). These leaves were cut from the branches and the amount of leaf tissue with damage attributed to fungi visually estimated for each leaf according to the following sigmoid scale classification: 0; 1–5; 6–10; 11–20; 21–50; 51–90; 91–95 and 96–100% (e.g. Horsfall & Barratt 1945) and then ranked from 0 to 7 corresponding to the estimated percentage classification. For example, an estimate of 10 to 20 percentage leaf tissue damaged would receive a score of 3. Any damage that was attributed to feeding by the psyllid *Glycaspis baileyi* was scored separately usually the same scoring method as for fungal damage. This species was the most abundant damage-causing agent present on the foliage sampled. The 20 leaves per branch were then photocopied and the images used to measure total leaf length; the ratio of maximum potential length along the midrib to maximum breadth and percentage leaf area missing because of insect herbivory, with a hand-held digital planimeter (Planinx7: Tamaya Technics Inc., Tokyo, Japan).

After being photocopied, the leaves of the young and mature age cohorts (Plots 3, 4, 5 and 6 only) were used for analysis of free hexose and total free amino acids content. A 10 nm diameter disc of tissue was obtained with a leaf punch from each leaf, avoiding the leaf midvein. The small leaf discs from each branch were placed into cryogenic vials, snap frozen in liquid nitrogen before transferal to a –80°C freezer. The material was ground in liquid nitrogen and extracted with 80% ethanol in a mortar and pestle. The extract was boiled for 30 minutes at 80°C before being centrifuged for five minutes. The supernatants were collected and the pellet re-extracted twice more. A sample of pooled supernatants was used to determine free amino acid concentration using the ninhydrin method of Moore & Stein (1948) using arginine to calibrate the test. Free hexoses were analysed as a measure of total soluble sugars using the anthrone method of Fales (1951). Glucose was used to calibrate the test. The ratio of free hexose to amino acid concentration was then calculated.

Table 2. Mean plot variables and tree-scale traits (mean ± standard deviation) from five mature *Eucalyptus saligna* per plot in sites in Cumberland State Forest presenting a range of crown dieback symptoms.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Plot variables						
Stem per ha†	2399	1807	4339	1977	169	3675
Mean stem diameter (cm)†	13.3 ± 2.2	12.6 ± 2.9	4.6 ± 0.9	8.8 ± 2.0	30.8 ± 10.1	5.9 ± 0.9
Presence of *Phytophthora cinnamomi* at base of tree‡	0.4 ± 0.5	0.4 ± 0.9	2.2 ± 1.3	2.2 ± 0.8	0.0 ± 0.0	1.2 ± 0.8
Tree traits from the five mature *Eucalyptus saligna*						
Height (m)	37.9 ± 7.6	36.2 ± 2.2	28.6 ± 4.7	31.6 ± 3.7	34.4 ± 4.3	30.5 ± 2.5
Diameter over bark at breast height (cm)	57.3 ± 12.5	55.9 ± 11.5	53.3 ± 6.9	54.1 ± 10.1	62.6 ± 18.5	49.4 ± 8.4
Diameter increment over 20 months, (cm)	1.7 ± 0.2	1.7 ± 0.7	-0.20 ± 0.9	0.9 ± 0.5	1.4 ± 0.8	0.5 ± 0.3
Tree Crown Condition Score*	13.9 ± 0.9	12.9 ± 1.1	7.5 ± 1.4	12.3 ± 0.5	14.6 ± 0.5	11.4 ± 1.3

† All stems diameters over 2.0 cm at DOBBH were measured irrespective of plant species

‡ Maximum detection score = 5.0; four soil samples per tree per plot, five trees per plot

* Crown condition was visually assessed using the crown scoring system for eucalypts presented in Stone *et al.* (2003, Appendix 2). Higher values indicate healthier crowns

Correlations among the soil, tree and leaf variables were examined by computing either Pearsons correlation coefficients (r) or Spearman rank correlation coefficients (r_s) depending on the normality of each attribute using the Corr Procedure in SAS System for Windows (SAS Institute Inc. 1987).

Results

Moisture content of the topsoil was not measured but during the first five months of 2002, Cumberland S.F received 550 mm of rainfall which is half the mean annual rainfall. White's Moisture Stress Index (MSI) calculated for the years 2001 and 2002 gave values of – 1.67 and – 1.87 respectively. High positive values of this index indicate a season of stressful weather; relatively large negative values signify an absence of stressful weather (White 1986). The most stressful year prior to this was 1997 with a value of + 2.01; MSI values gradually declined over the next 5 years.

Structure and crown measurements

Stands dominated by *Eucalyptus saligna* exhibit a range of floristic structure and condition (Fig. 2A–F, Tables 1 and 2). Plot 1 with the tallest *Eucalyptus saligna* trees and healthy crowns (Table 2) was in a site subjected to a hazard reduction burn 20 years previously, and that can become briefly inundated during high rainfall events. Compared to the other plots, it possessed a relatively dense overstorey but there was little ground cover or lower midstorey present (Fig. 2A). In Plot 2, located 200 metres east of plot 1 at slightly higher elevation, the *Eucalyptus saligna* crowns were of moderate condition, but the stems were gaining increment at a similar rate as trees in plot 1 (Table 2). The density of overstorey trees was lower than plot 1 and a more pronounced midstorey existed (Fig. 2B). Bell miners were not recorded in any of the three southern plots (plots 1, 2 and 6, Table 3).

The *Eucalyptus saligna* trees in plot 3, the only plot permanently colonized by bell miners, were in the poorest condition (Table 2) and several dead trees of *Eucalyptus saligna* and *Eucalyptus paniculata* were observed in the plot. The high stem density was due to a dense mid-storey dominated by exotics including lantana (Table 1, Fig. 2C) and the plot included an area that had been subjected to a low intensity fire in 1993. In Plot 4, approximately 100 m downslope from Plot 3, the *Eucalyptus saligna* crowns were of moderate condition but no dead trees were present (Table 2). The midstorey was less mesic than the understorey in plot 3 (Table 1) and of lower density, due in part to the selective, manual removal of *Pittosporum revolutum*. Bell miners were observed to fly occasionally into plot 4 from the adjacent area, that included plot 3, but during the 3 years of bird counts, had not been observed to nest in plot 4 (Table 3). Plot 5, the third plot comprising the northern cluster of plots, differed significantly from the others in several ways. A midstorey was non-existent and groundcover was dominated by exotic grasses (Fig. 1E). There was a relatively low density of mature *Eucalyptus saligna* and all five crowns were assessed as very healthy (Table 2). Occasionally a few bell miners would fly over from the area of plot 3 and then return (Table 3). Plot 6 was located on the south-western side of Cumberland S. F. It was similar to Plot 3 in having a relatively dense midstorey (Fig. 1F) and the area had been burnt in 1993. The *Eucalyptus saligna* crowns were of moderate condition (Table 2). No bell miners were observed in the stand during the 3 year bird count survey.

Pathogens

Phytophthora cinnamomi was detected in some soil samples from all plots, except plot 5 (Table 2). All the isolates were A2 mating type. Trace levels of *Phytophthora cinnamomi* were detected in plots 1 and 2, while plots 3 and 4 had the highest detected levels (Table 2). No evidence of infection of trees or stumps by *Armillaria luteobubalina* was found in any of the plots.

Comparison of soil variables between plots

The topsoil samples from each plot was moderately acidic and did not differ noticeably with respect to pH (water), electrical conductivity, and total soluble salts (Table 4). Plot 5, the only plot without a midstorey component (Fig. 1E), had notably less organic matter and oxidisable organic matter in the topsoil than the other five plots. The mean percent of total nitrogen (w/w) ranged from 0.17 in plot 1 to 0.35 in plot 6. The plots differed noticeably in the carbon/nitrogen

Table 3. Bell miner bird counts in Cumberland State Forest. Birds counts from 0.28 ha circular plots, converted to average bird counts per ha. Range in brackets.

Bell miner counts	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Spring 2001	0	0	82	13	N.A	0
			(106 – 71)	(0 – 21)	.	
Autumn 2002	0	0	88	21	4	0
			(124 – 74)	(0 – 32)	(0 – 7)	
Spring 2003	0	0	94	11	2	0
			(134 – 74)	(0 – 18)	(0 – 4)	

Table 4. Selected soil chemical properties (means ± standard deviation) of the topsoil (0-15 cm) from near the base of five mature *Eucalyptus saligna* in six plots presenting a range of crown symptoms in Cumberland State Forest.

Soil properties	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
pH (water)	5.68 ± 0.19	5.02 ± 0.23	5.54 ± 0.28	5.46 ± 0.26	5.84 ± 0.11	5.38 ± 0.14
Electrical conductivity (dS/m)	0.064 ± 0.004	0.062 ± 0.004	0.067 ± 0.015	0.074 ± 0.005	0.072 ± 0.005	0.080 ± 0.007
Total soluble salts (%w/w)	0.02 ± 0.0	0.02 ± 0.0	0.024 ± 0.005	0.024 ± 0.005	0.022 ± 0.004	0.028 ± 0.004
Organic matter (%w/w)	8.20 ± 0.78	12.42 ± 2.85	7.80 ± 1.91	3.94 ± 3.40	1.52 ± 0.35	3.62 ± 3.51
Oxidisable organic carbon (% w/w)	4.32 ± 0.18	6.50 ± 1.40	4.10 ± 1.01	2.06 ± 1.79	0.78 ± 0.19	1.89 ± 1.84
Total nitrogen (% w/w)	0.17 ± 0.03	0.25 ± 0.04	0.26 ± 0.06	0.24 ± 0.03	0.24 ± 0.05	0.35 ± 0.02
Carbon/Nitrogen ratio	26.4 ± 4.5	25.7 ± 2.5	15.7 ± 1.2	8.4 ± 7.2	3.5 ± 1.2	5.7 ± 6.2
Exchangeable calcium (meq/100g)	2.94 ± 1.51	2.16 ± 0.86	2.48 ± 1.21	3.00 ± 0.72	5.74 ± 0.59	3.14 ± 0.53
Exchangeable magnesium (meq/100g)	3.40 ± 0.75	1.94 ± 0.44	3.32 ± 0.86	3.16 ± 0.3	3.68 ± 0.694	3.56 ± 0.49
Echangeable sodium (meq/100g)	0.26 ± 0.04	0.16 ± 0.02	0.28 ± 0.07	0.33 ± 0.06	0.26 ± 0.05	0.43 ± 0.05
Exchangeable potassium (meq/100g)	0.42 ± 0.07	0.39 ± 0.03	0.62 ± 0.23	0.55 ± 0.06	0.72 ± 0.15	0.53 ± 0.07
Sum of the 4 cations (meq/100gm)	7.08 ± 2.17	4.68 ± 1.31	6.76 ± 2.14	7.08 ± 0.93	10.36 ± 2.12	7.70 ± 1.12
Calcium/Magnesium ratio (meq/100gm)	0.86 ± 0.35	1.12 ± 0.19	0.78 ± 0.25	0.98 ± 0.19	1.58 ± 0.19	0.92 ± 0.08

Table 5. Mean leaf-scale traits (mean± standard deviation) measured from foliage of five mature *Eucalyptus saligna* per plot in Cumberland State Forest presenting a range of crown dieback symptoms.

n = 200 for variables measured from six plots and *n* = 40 for variables measured from four plots. All leaves of similar age being mature and initiated in the current growing season.

Fungal damage score and *Glycaspsis* damage score: 0% leaf area affected = 0; 1-5% = 1, 6-10% = 2, 10-20% = 3, 20-50% = 4, 50-90% = 5; 91-95% = 6, 96 – 100% = 7

Leaf traits	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6
Morphological variables						
Total length (mm)	159.3 ± 1.6	121.8 ± 2.1	110.7 ± 2.4	117.0 ± 2.0	131.9 ± 2.4	143.5 ± 2.6
Ratio of max. leaf length to max. leaf breadth	5.7 ± 0.1	3.4 ± 0.1	3.2 ± 0.08	3.4 ± 0.07	4.4 ± 0.08	4.3 ± 0.08
Total potential leaf area (cm^2)	29.9 ± 0.58	31.5 ± 0.75	28.6 ± 0.77	30.2 ± 0.75	27.8 ± 0.71	36.7 ± 2.10
Damage variables						
Percentage leaf area missing due to insect herbivory	0.9 ± 2.1	3.2 ± 5.4	2.2 ± 5.1	5.0 ± 7.5	2.7 ± 4.9	2.4 ± 3.9
Fungal damage score	0.21 ± 4.3	0.34 ± 0.59	0.15 ± 0.48	0.29 ± 0.59	0.28 ± 0.42	0.32 ± 0.56
Glycaspsis damage score	0.0	0.0	2.3 ± 0.8	0.0	0.0	0.0
Physiological variables						
Relative measure of chlorophyll content (SPAD) values)	46.3 ± 4.1	44.4 ± 3.5	41.1 ± 4.8	46.4 ± 5.3	47.0 ± 3.3	48.3 ± 3.8
Ratio of variable to maximum chlorophyll fluorescence (Fv/Fm)	0.83 ± 0.01	0.83 ± 0.01	0.81 ± 0.03	0.83 ± 0.02	0.84 ± 0.01	0.84 ± 0.01
Free Hexose (mg Hexose g Leaf Dry Weight^{-1})			7.5 ± 4.8	9.4 ± 5.0	8.3 ± 3.3	9.7 ± 2.2
Free amino acids (mg amino acids g LDW^{-1})			57.9 ± 31.5	38.0 ± 27.1	20.4 ± 13.2	12.0 ± 4.7

(C/N) ratio of the topsoil (Table 4). Plots 1 and 2 had much higher C/N ratios than plots 4, 5 and 6. Plot 3, the plot with the visually unhealthiest *Eucalyptus saligna* crowns had a mean C/N of 15.7 which is in the mid range of values (3.48 to 26.4). Crown condition scores were weakly negatively correlated with both higher topsoil organic C content (%w/w) ($r_s = -0.37$, $P = 0.034$, $n = 30$) and total N ($r_s = -0.34$, $P = 0.064$, $n = 30$) and not correlated to the C/N ratio.

The soil samples from the six plots did not differ notably in cations; calcium, magnesium, sodium, and potassium, except that plot 5 had more exchangeable calcium than the other plots. Correlations based on rank scores, were significant between tree crown condition score and the topsoil sampled at the base of each tree for pH ($r_s = 0.55$, $P = 0.002$, $n = 30$), calcium content (meq/100g) ($r_s = 0.392$, $P = 0.032$, $n = 30$); and the calcium/magnesium ratio ($r_s = 0.51$, $P = 0.004$, $n = 30$), however, examination of the individual scatterplots revealed high variation associated with these trends.

Comparison of leaf-scale traits

Mature leaves from plots 5 and 1 were the most lanceolate in shape with larger leaf length to breadth ratios, while the leaves from unhealthy trees in plot 3 were the broadest in shape (Table 5). All leaves sampled had relatively low levels of tissue damage from fungal infections or insect herbivory. Damage by species of *Mycosphaerella* and their anamorphs, and other Ascomycota were negligible (Table 5). Leaves from plot 1 had virtually no insect damage while leaves from plot 4 had, on average, approximately 5% leaf area missing (Table 5). The exception was the impact of the sap-sucking psyllid, *Glycaspis baileyi*, on leaves of *Eucalyptus saligna* trees in plot 3. The twenty mature leaves per branch assessed had approximately 10% leaf tissue damaged from *Glycaspis* feeding. Leaves from plot 3 also had the lowest relative chlorophyll content (SPAD units) and values of the chlorophyll fluorescence parameter F_v/F_m (Table 5). Not surprisingly, both relative chlorophyll content and chlorophyll fluorescence were significantly correlated with *Glycaspsis* score ($r = -0.742$ and -0.740, $P < 0.001$). These two photosynthetic leaf traits were also significantly correlated with leaf shape (length / breadth ratio) ($r = 0.508$ and 0.467, $P < 0.01$). When all leaves infested with *Glycaspis* were removed from the data set, a similar relationship remained but was weaker ($r = 0.35$ and 0.29, $P > 0.05$).

The foliar content of soluble sugars, as measured by free hexoses, did not differ much between plots 3, 4, 5 and 6 though there were large differences in free amino acid content among these plots (Table 5). Leaves from plot 3 had the highest mean content of free amino acids while leaves from plot 6 had the lowest (Table 5). Both free amino acid content and the ratio of free hexose to free amino acids were significantly correlated to relative chlorophyll content ($r = -0.810$ and 0.755 respectively, $P < 0.001$). These two chemical leaf variables were also significantly correlated with *Glycaspis* score ($r_s = 0.650$ and -0.660 respectively, $P < 0.001$). When leaves infested with *Glycaspis* were removed from the data set, this relationship was still significant ($r_s = -0.682$ and 0.582, $P < 0.01$). This trend appears to exist across all leaves sampled and not just leaves affected by *Glycaspis* feeding. The presence of *Glycaspis* seems to strengthen the relationship between increasing free amino acid content with decreasing chlorophyll content (SPAD units). There was also a significant negative correlation between leaf shape (leaf length and leaf length to breadth ratio) and free amino acid content. Leaves lanceolate in shape had less free amino acid content than shorter and or rounder leaves (while for chlorophyll content the reverse was true). This trend is maintained in the absence of *Glycaspis* but is statistically weaker. The mean free amino acid content of all leaves sampled and classed as young leaves was higher (40.7 ± 12.9 mg amino acids g LDW^{-1}) (mean ± standard deviation) than the mean free amino acid content of the mature leaves sampled (31.7 ± 25.8 mg amino acids g LDW^{-1}).

Discussion

The bell miner plot (plot 3) had *Eucalyptus saligna* crowns in the poorest condition and negative stem diameter increments for some trees indicated that they were dying. Plot 3 also had a dense mesic understorey dominated by exotic species including lantana, though lantana was also present in plots 4 and 6, but not to the same extent as in plot 3, because of manual weed removal. Although plot 5 was near plot 3, and occasionally frequented by the bell miners, the *Eucalyptus saligna* trees in this plot were healthy, but as this site was maintained as a picnic site a midstorey did not exist. Using data from a survey of eucalypt crown dieback in north-eastern NSW, Stone et al. (1995) concluded that although lantana was commonly correlated with the presence of bell miners there was not a linear trend, and bell miners appeared to prefer a dense shrubby understorey for nesting sites, irrespective of plant species composition (Stone 2005). Lantana prefers warm, moist sites with partial shade or patchy sunlight (Swarbrick et al. 1998), and under these conditions can dominate the understorey and suppress regeneration of native plant species. While lantana may not be a primary causal factor initiating dieback of *Eucalyptus saligna*, it can persist in the presence of this crown syndrome.

Pathogens

The soil-borne pathogen *Phytophthora cinnamomi* was isolated from all plots except plot 5. Hundreds of native plant species are known to be susceptible *Phytophthora cinnamomi* (Shearer & Smith 2000), and within *Eucalyptus*, species of *Monocalyptus* tend to be the most susceptible, though *Eucalyptus saligna* is generally regarded as relatively resistant (Tippett et al. 1985; Gerrettson-Cornell 1973). Nevertheless, the susceptibility of unhealthy *Eucalyptus saligna* to infection from *Phytophthora cinnamomi* is likely to be greater than that of healthy trees (Gerrettson-Cornell

1973). Several studies have demonstrated a strong relationship between the distribution of *Phytophthora cinnamomi* and soil moisture (e.g. McDougall et al. 2002) with the fungus being difficult to isolate during dry conditions. The site distribution of *Phytophthora cinnamomi* is therefore influenced by factors such as drainage, as well as the presence of susceptible hosts (e.g. Marks et al. 1975). *Armillaria luteobubalina* was not detected in any of the plots.

Soil factors

A comparison of the chemical properties of the topsoil of the Hawkesbury Sandstone (plots 1 and 2) with Ashfield Shale soils (plots 3, 4, 5 and 6) did not reveal noticeable differences, except perhaps the slightly lower mean calcium content for the plots on sandstone. Other factors that could contribute to the observed variation in organic carbon and nitrogen content of the topsoil in Cumberland S.F. include nutrient run-off from neighbouring urban properties and roads, soil disturbance through regular but patchy weed management, and changes in the composition of the understorey (e.g. Granger et al. 1994). Hazard reduction burns in plots 1, 3 and 6 were done approximately 8 years before plot assessment but the residual effects from these low intensity burns are assumed to be minimal.

In general, crown condition scores were weakly negatively correlated with topsoil organic C content and total N. The *Eucalyptus saligna* trees in plot 1 (the creek plot) were relatively healthy (high crown condition scores), even though the plot was occasionally inundated after heavy rain. Nor did these trees appear to be limited by the lowest mean total N content recorded from the six plots. The only plot without a distinct midstorey, plot 5, also had healthy *Eucalyptus saligna* trees; it also had the lowest organic matter and percent carbon in the topsoil among the six plots.

Numerous published studies have demonstrated that concentration of ammonium nitrogen in the topsoil can be promoted by fire (e.g. Polglase et al. 1986; Weston & Attiwill 1990; Neave & Raison 1999) but this effect is only temporary due to rapid immobilisation of ammonium (and nitrate) by soil microfauna over several months (e.g. Adams & Attiwill 1986; Weston & Attiwill 1990). It is this period after a fire that allows for the rapid establishment of ammonium assimilating eucalypt species, providing other site factors, including adequate soil moisture, sunlight and viable seed, are non-limiting (e.g. King 1985; Nicholson 1999). Frequent low-intensity fires could result in replacing a mesic understorey with fire-tolerant species producing litter of higher C/N ratios (e.g. Guinto 2001) and reduced soil moisture (e.g. York 1999). These soil conditions might promote the ammonifying heterotrophic component of the soil microflora, and thereby provide a competitive advantage to eucalypt species that assimilate ammonium nitrogen over nitrophilic species, but these assumptions require further examination.

Leaf scale relationships

Tissue damage on individual mature leaves was relatively low (cf. Stone 1996) except on leaves from *Eucalyptus saligna* in the plot colonised by the bell miners (plot 3). These leaves were heavily infested with the lerp-forming psyllid *Glycaspis baileyi*. *Glycaspis* species are phloem feeders and initiate their feeding sites on developing leaf flush which are photosynthetic sinks (Woodburn & Lewis 1973). The reddish – purple discolouration associated with *Glycaspis baileyi* feeding is due to localised accumulation of anthocyanins that has been linked to photoinhibition (Close et al. 2003) arising from impairment of the photosynthetic apparatus in tissue damaged by psyllid feeding. This relationship was supported in this study by the significant linear correlations between the damage score for *Glycaspis* and relative chlorophyll content (SPAD units) and photosynthetic efficiency (F_v/F_m) measured from the mature foliage. The broader shape of the mature leaves from plot 3, compared to the other plots, is indicative of replacement foliage, which for some eucalypt species, has been shown to have chemical and physical characteristics more in common with immature leaves than mature foliage (e.g. Landsberg 1990).

Phloem feeders obtain their nitrogen nutrition from free amino acids, amides and small polypeptides (Brodbeck & Strong 1987). Assays of total nitrogen do not indicate the nutritional quantity for phloem feeders because total nitrogen also includes compounds, such as insoluble proteins and nitrogen-based secondary compounds of little nutritional value to these insects (Mattson 1980). The mature leaves sampled from plot 3 had higher mean concentrations of free amino acids than similar aged foliage from plots 4, 5 and 6. The observed negative correlation between foliar chlorophyll content and free amino acids appeared to be strengthened by *Glycaspis* feeding.

In addition to localised cellular damage associated with insect feeding (e.g. Taylor 1997), other processes have been identified as influencing the soluble nitrogen content of leaves in tree crowns including: leaf age; environmental stresses, and soil nutrition (e.g. Stewart & Larher 1980; Brodbeck & Strong 1987; Adams & Atkinson 1991; Adams et al. 1995; Marsh & Adams 1995). This study demonstrated that, on average, younger leaves had a higher free amino acid content than mature leaves. Other studies have also shown younger eucalypt foliage to have a higher free amino acid content and lower chlorophyll content than mature leaves (Journet & Cochrane 1978; Adams et al. 1995; Taylor 1997, Choinski et al. 2003, Stone et al. 2005). Younger eucalypt foliage also has lower specific leaf weight (dry wt per unit area) compared to mature foliage, and hence is more palatable to insect leaf chewers, such as chrysomelid larvae (e.g. Ohmart 1991; Steinbauer 2001; Lawrence et al. 2003).

Most eucalypt species have seasonal patterns of new leaf production, but many are also opportunistic, responding quickly to improved conditions, for example, a rainfall event. A flush of new foliage (epicormic growth) can also be initiated after rapid defoliation from an outbreak of insects (e.g. cup moths *Doratifera* spp.). Epicormic refoliation is also a common response after crown damage from drought, fire or frost (e.g. Gill 1997). *Glycaspis baileyi* is a multivoltine insect having six or seven generations per year (Moore 1961), and has the capacity to respond quickly to altered crown phenology such as a foliar flushing event. White (1971) observed that female *Glycaspis brimlecombei* females usually, but not always, lay their eggs on soft young leaves that are still expending.

Increased leaf production can also be induced by increased irradiation penetration of the canopy, through windthrow, selective logging or edge effects from roads or rural clearings. Leuning *et al.* (1991) observed that foliar nitrogen is distributed within *Eucalyptus grandis* crowns according to the prevailing light environment. This is because eucalypt foliage receiving high irradiation has greater photosynthetic capacity and hence higher nitrogen content than shaded leaves (Leuning *et al* 1991; Sands 1996). Medhurst (2000) and Pinkard *et al.* (1998) demonstrated that thinning of *Eucalyptus nitens* plantations improved irradiation penetration to the lower leaves of tree crowns, and this in turn, resulted in the initiation of more leaves over a greater area of the crown (i.e. increased tree leaf area).

Numerous studies have also reported the positive response by herbivorous insects to the sun-lit portions of tree crowns. White (1970), for example, reported that although eggs of the psyllid *Cardiaspina densitexta* were laid on the lower shaded side of individual leaves of *Eucalyptus fasciculosa*, greater numbers of eggs were laid on the northern side of tree crowns compared to the southern side. Populations of the aphid, *Essigella californica*, were found to be significantly higher on the upper crowns of trees growing on north-facing sunny aspects in comparison of other aspects (Appleton et al. 2003). Therefore eucalypt tree crowns responding to increased penetration of sun light into the canopy would possess a greater proportion of expanding foliage favourable to psyllids, as well as many leaf chewing insects (Ohmart 1991) compared to more shaded crowns. Medhurst (2000) demonstrated that the enhanced photosynthesis in the mid and lower sections of the *Eucalyptus nitens* crowns disappeared after canopy closure.

Stressful environmental processes have been shown to also influence the physiological function of leaves. Numerous definitions of plant stress have been proposed (e.g. Jones & Jones. 1989). Waring (1991) examined plant stress in terms of damaging processes or agents causing a reduction in photosynthetic CO_2 assimilation. While one indicator of reduced photosynthesis is the reduction in foliar production (e.g. Whitehead & Beadle 2004), another is the mobilisation of soluble nutrients including free amino acids (Brodbeck & Strong 1987). In our study, the White's Moisture Stress Index values indicated that the trees in Cumberland S.F. were not under soil moisture stress at the time of plot assessment in 2002, but would have suffered moisture stress in 1997 (stress index = +2.01).

Conclusions

The data from this survey supports the findings of others (e.g. Loyn et al. 1983; Stone 1996; Clarke & Schedvin 1999) of a strong association between the presence of bell miners, leaf damage from sap-sucking insects, and eucalypt crown decline. Conditions that contribute to the success of bell miner colonies also directly or indirectly contribute to this form of crown decline. This study has also demonstrated a correlation between psyllid population levels and foliage condition, including the phenology and nutritional status of the leaves. Clarke and Schedvin (1999) reported that bell miners were capable of re-establishing a small colony before psyllid numbers had risen to high levels, and that after bell miners had gained control of the site again, psyllid numbers rose substantially. Nevertheless, it is assumed that newly-founded colonies would benefit if the tree crowns had the initial capacity to carry high populations of herbivorous insects. Site factors that might improve both the quantity and quality of available foliage, to which populations of herbivorous insects would respond, have been discussed. Controlled experimental field studies are now required to confirm and quantify the influence of these factors on the initiation and maintenance of bell miner associated dieback. Further studies are also needed on the effects of *Phytophthora cinnamomi* on growth and vigour of mature *Eucalyptus saligna* trees in the presence or absence of bell miner colonies.

Acknowledgements

We thank Grahame Price and Darren Waterson (NSW DPI Science & Research), and Amelia Jones (Forests NSW) for their technical assistance. The plot bird counts were done by Matthew Stanton (NSW DPI Science & Research) and leaf analysis for free hexose and amino acid concentrations undertaken by Matthew Searson (University of Western Sydney). Their contribution to this study is appreciated. John Raison (CSIRO FFP), Lorraine Spohr (NSW DPI Science & Research) and Ross Florence provided comments that improved this manuscript. The chemical soil analysis was done at the Victorian State Chemistry Laboratory, Dept. of Natural Resources & Environment, Werribee. Financial support for the soil and foliar analyses was provided by the Cumberland S.F. management unit and Baulkham Hills Shire Council is gratefully acknowledged.

References

Adams, M.A. & Atkinson, P.I. (1991) Nitrogen supply and insect herbivory in eucalypts: the role of nitrogen assimilation and transport processes. In: *Productivity in perspective. Proceedings Third Australian Forest Soils and Nutrition Conference* (ed. P.J. Ryan). pp. 67–75. (Forestry Commission of NSW: Sydney)

Adams, M.A. & Attiwill, P.M. (1986) Nutrient cycling and nitrogen mineralization in eucalypt forests of south-eastern Australia. II Indices of nitrogen mineralization. *Plant Soil* 92: 341–362.

Adams, M.A., Attiwill, P.M. & Wang, L.M. (1995) Effects of phosphorous supply on growth and nitrogenous fractions in xylem sap and foliage of *Eucalyptus regnans* (F.Muell.), *E. nitens* (Maiden) and *E. globulus* (Labill.) seedlings: implications for herbivory. *Trees* 9: 324–331.

Appleton, C., Gresham, B.A. & Zydenbos, S.M. (2003) Monitoring *Essigella californica* populations in Bay of Plenty forests. *New Zealand Plant Protection* 56: 45–50.

Bennett, L.T. & Adams, M.A. (2004) Assessment of ecological effects due to forest harvesting: approaches and statistics issues. *Journal of Applied Ecology* 41: 585–598.

Brodbeck, B. & Strong, D. (1987) Amino acid nutrition of herbivorous insects and stress to host plants. In: *Insect outbreaks* (eds. P. Barbosa & J.C. Schultz). pp. 347–363. (Academic Press Inc.: San Diego)

Chee, K.H. & Newhook, F.J. (1965) Improved methods for use in studies on *Phytophthora cinnamomi* Rands and other *Phytophthora* species. *New Zealand Journal of Agricultural Research* 8: 88–95.

Choinski, J.S., Ralph, P. & Eamus, D. (2003) Changes in photosynthesis during leaf expansion in *Corymbia gummifera*. *Australian Journal of Botany* 51: 111–118.

Clarke, M.F. & Fitz-Gerald, G.F. (1994) Spatial organisation of the co-operatively breeding bell miner *Manorina melanophrys*. *Emu* 94: 96–105.

Clarke, F.C. & Schedvin, N. (1999) Removal of bell miners *Manorina melanophrys* from *Eucalyptus radiata* forest and its effect on avian diversity, psyllids and tree health. *Biological Conservation* 88: 111–120.

Close, D., McArthur, C., Paterson, S., Fitzgerald, H., Walsh, A. & Kincade, T. (2003) Photoinhibition: A link between effects of the environment on eucalypt leaf chemistry and herbivory. *Ecology* 84: 2952–2966.

Edgar, J.G., Kile, G.A. & Almond, C.A. (1976) Tree decline and mortality in selectively logged eucalypt forests in central Victoria. *Australian Forestry* 39: 288–303.

Ellis, R.C. (1985) The relationships among eucalypt forest, grassland and rainforest in a highland area in north-eastern Tasmania. *Australian Journal of Ecology* 10: 297–314.

Ellis, R.C. & Pennington, P.I. (1989) Nitrification in soils of secondary vegetational successions from *Eucalyptus* forest and grassland to cool temperate rainforest in Tasmania. *Plant Soil* 115: 59–73.

Fales, F.W. (1951) The assimilation and degradation of carbohydrates by yeast cells. *Journal of Biological Chemistry* 193: 113–121.

Forestry Commission of New South Wales (1984) *Management Plan for Cumberland Management Area.* (Forestry Commission of NSW: Sydney).

Forestry Commission of New South Wales (1989) *Forest Types in New South Wales. Research Note No. 17.* (Forestry Commission of NSW: Sydney).

Gerrettson-Cornell, L. (1973) The recovery of *Phytophthora cinnamomi* Rands from Ourimbah State Forest (Wyong, Newcastle District, New South Wales, Australia) and its pathogenicity to eucalypt seedlings under controlled conditions. *Phyton* 31: 111–116.

Gill, A.M. (1997) Eucalypts and fires: interdependent or independent ? In: *Eucalypt ecology: individuals to ecosystems* (eds. J.E. Williams & J.C.Z. Woinarski). pp.151–167. (Cambridge University Press: Cambridge).

Granger, L., Kasel, S. & Adams, M.A. (1994) Tree decline in southeastern Australia: Nitrate reductase activity and indications of unbalanced nutrition in *Eucalyptus ovata* (Labill.) and *E. camphora* (R.T. Baker) communities at Yellingo, Victoria. *Oecologia* 98: 221–228.

Guinto, D.F., Xu, Z., House, A.P.N. & Saffigna, P.G. (2001) Soil chemical properties and forest floor nutrients under repeated prescribed-burning in eucalypt forests of south-east Queensland, Australia. *New Zealand Journal of Forest Science* 31: 170–187.

Horsfall, J.G. & Barratt, R.W. (1945) An improved grading system for measuring plant diseases. *Phytopathology* 35: 655.

Jones, H.G. & Jones, M.B. (1989) Introduction: Some terminology and common mechanisms. In: *Plants under stress* (eds. H.G. Jones, T.J. Flowers & M.B. Jones). pp. 1–10. (University Press: Cambridge).

Journet, A.R.P. & Cochrane, P.M. (1978) Free amino acids in leaf tissue of *Eucalyptus blakelyi*. *Phytochemistry* 17: 1789–1790.

Jurskis, V. (2005) Eucalypt decline in Australia, and a general concept of tree decline and dieback. *Forest Ecology and Management* 215: 1–20.

Jurskis, V. & Turner, J. (2002) Eucalypt dieback in eastern Australian: a simple model. *Australian Forestry* 65: 87–98.

Kile. G.A. (1974) Insect defoliation in the regrowth forests of Tasmania. *Australian Forestry Research* 6: 9–18.

Kile, G.A. (1980) Behaviour of an *Armillaria* in some *Eucalyptus obliqua-Eucalyptus regnans* forests in Tasmania and its role in their decline. *European Journal of Forest Pathology* 10: 248–296.

King. G.C. (1985) Natural regeneration in wet sclerophyll forest with an overstorey of *Eucalyptus microcorys*, *E. saligna*, and *Lophostemon confertus*. *Australian Forestry* 48: 54–62.

Landsberg, J. (1990) Dieback of rural eucalypts: Does insect herbivory relate to dietary quality of tree foliage. *Australian Journal of Ecology* 15: 73–87.

Landsberg, J. & Wylie, F.R. (1988) Dieback of rural trees in Australia. *Geo Journal* 17.2: 231–237.

Lawrence, R., Potts, B.M. & Whitham, T.G. (2003) Relative importance of plant ontogeny, host genetic variation, and leaf age for a common herbivore. *Ecology* 84: 1171–1178.

Leuning, R., Cromer, R.N. & Rance, S. (1991) Spatial distributions of foliar nitrogen and phosphorus in crowns of *Eucalyptus grandis*. *Oecologia* 88: 504–510.

Loyn, R.H., Runnals, R.G. & Tyers, J. (1983) Territorial bell miners and other birds affecting populations of insect prey. *Science* 221: 1411–1412.

Marks, G.C., Kassaby, F.Y. & Fagg, P.C. (1975) Variation in population levels of *Phytophthora cinnamomi* in *Eucalyptus* forest soils of eastern Victoria. *Australian Journal of Botany* 23: 435–449.

Marsh, N.R & Adams, M.A. (1995) Decline of *Eucalyptus tereticornis* near Bairnsdale, Victoria: Insect herbivory and nitrogen fractions in sap and foliage. *Australian Journal of Botany* 43: 39–50.

Mattson, W. (1980) Herbivory in relation to plant nitrogen content. *Annual Review of Ecological Systematics* 11: 119–161.

McDougall, K.L., Hardy, G.E. St J. & Hobbs, R.J. (2002) Distribution of *Phytophthora cinnamomi* in the northern jarrah (*Eucalyptus marginata*) forest of Western Australia in relation to dieback age and topography. *Australian Journal of Botany* 50: 107–114.

Medhurst, J.L. (2000) Growth and physiology of *Eucalyptus nitens* in plantations following thinning. (PhD Thesis: School of Plant Science, University of Tasmania).

Moore, K.M. (1961) Observations on some Australian forest insects. 8. The biology and occurrence of *Glycaspis baileyi* Moore in New South Wales. *Proceedings of Linnean Society of New South Wales* 86: 185–200.

Moore, S. & Stein, W.H. (1948) Photometric ninhydrin method for the use in the chromatography of amino acids. *Journal of Biological Chemistry* 176: 367–388.

Neave, I.A. & Raison, R.J. (1999) Soil nitrogen availability under forests of contrasting composition and structure in south eastern New South Wales, and the effects of simulated harvesting disturbance and fire. *Australian Forestry* 62: 1–8.

Nicholson, E. (1999) Winds of change for silvicultural practice in NSW native forests. *Australian Forestry* **62:** 223–235.

Ohmart, C.P. (1991) Role of food quality in the population dynamics of chrysomelid beetles feeding on *Eucalyptus. Forest Ecology Management* 39: 35–46.

Old, K.M. (2000) Eucalypt diseases of complex etiology. In: *Diseases and pathogens of eucalypts* (eds. P.J. Keane, G.A. Kile, F.D. Podger & B.N. Brown). pp.411–425. (CSIRO Publishing: Collingwood).

Old, K.M., Gibbs, R., Craig, I., Myers, B.J. & Yuan, Z.Q. (1990) Effect of drought and defoliation on the susceptibility of eucalypts to cankers caused by *Endothia gyrosa* and *Botryosphaeria ribis. Australian Journal of Botany* 38: 571–581.

Pinkard, E.A., Beadle, C.L., Davidson, N.J. & Battaglia, M. (1998) Photosynthetic responses of *Eucalyptus nitens* (Deane and Maiden) Maiden to green pruning. *Trees* 12: 119–129.

Podger, F.D., Kile, G.A., Turnbull, C.R.A. and McLeod, D.E. (1980) An unexplained decline in some forests of Eucalyptus oblique and E. regnans in southern Tasmania. *Australian Forest Resources* 10: 54–70.

Podger, F.D. (1981) Some difficulties in the diagnosis of drought as the cause of dieback. In: *Eucalypt dieback in forests and woodlands* (eds. K.M. Old, G.A. Kile & C.P. Ohmart). pp. 167–173. (CSIRO Publishing: Melbourne).

Polglase, P.J., Attiwill, P.M. & Adams, M.A. (1986) Immobilization of soil nitrogen following wildfire in two eucalypt forests of south-eastern Australia. *Acta Oecologia* 7: 261–271.

Rayment, G.E. & Higginson, F.R. (1992) *Australian handbook of soil and water chemical methods.* (Inkata Press: Melbourne).

Sands, P.J. (1996) Modelling canopy production. III Canopy light-utilisation efficiency and its sensitivity to physiological and environmental variables. *Australian Journal of Plant Physiology* 23: 103–114.

SAS Institute Inc. (1987) *SAS/STAT Guide for Personal Computers, Version 6 Edition.* (SAS Institute Inc.: Cary, North Carolina).

Schreuder, H.T. & Thomas, C.E. (1991) Establishing cause-effect relationships using forest survey data. *Forest Science* 37: 1497–1512.

Shearer, B.L. & Smith, I.W. (2000) Diseases of eucalypts caused by soilborne species of *Phytophthora* and *Pythium*. In: *Diseases and pathogens of eucalypts.* (eds. P.J. Keane, G.A. Kile, F.D. Podger & B.N. Brown). pp. 259–291. (CSIRO Publishing: Melbourne).

Shields, J.M. (1990) *The effect of logging on bird populations in southeastern New South Wales.* (PhD Thesis: University of Washington, Seattle, Washington).

Steinbauer, M. (2001) Specific leaf weight as an indicator of juvenile leaf toughness in Tasmanian bluegum (*Eucalyptus globulus* ssp. *globulus*): implications for insect defoliation. *Australian Forest* 64: 32–37.

Stewart, G.R. & Larher, F. (1980) Accumulation of amino acids and related compounds in relation to environmental stress. In: *The Biochemistry of Plants vol. 5* (ed. B.J. Miflin). pp. 609–635. (Academic Press Inc.: New York).

Stewart, G.R., Gracia, C.A., Hegarty, E.E. & Specht, R.L. (1990) Nitrate reductase activity and chlorophyll content in sun leaves of subtropical Australian closed-forest (rainforest) and open-forest communities. *Oecologia* 82: 544–551.

Stone, C. (1996) The role of psyllids (Hemiptera: Psyllidae) and bell miners (*Manorina melanophrys*) in canopy dieback of Sydney blue gum (*Eucalyptus saligna* Sm.). *Australian Journal of Ecology* 21: 450–458.

Stone, C. (1999) Assessment and monitoring of decline and dieback of forest eucalypts in relation to ecologically sustainable forest management: a review with a case history. *Australian Forestry* 62: 51–58.

Stone, C. (2005) Bell miner associated dieback at the tree crown scale: A multi-trophic process. *Australian Forestry* 68: 237–241.

Stone, C, Spole, D. & Urquhart, C.A. (1995) *Survey of crown dieback on moist hardwood forests in the central and northern regions of New South Wales State Forests (psyllid/bell miner research programme).* Research Paper No. 28. (State Forests of NSW: Sydney).

Stone, C., Chisholm, L. & McDonald, S. (2005) Effects of leaf age and psyllid damage on the spectral reflectance properties of *Eucalyptus saligna* foliage. *Australian Journal of Botany* 53: 45–54.

Stone, C., Wardlaw, T., Floyd, R., Carnegie, A., Wylie, R., & de Little, D. (2003) Harmonisation of methods for the assessment and reporting of forest health in Australia – a starting point. *Australian Forestry* 66: 233–246.

Swarbrick, J., Wilson, B. & Hannan-Jones, M. (1998) *Lantana camara* In: *The biology of australian weeds.* Vol 2. (eds. F.D. Panetta, R.H. Groves, R.C.H. Shepherd). pp. 119–136. (RG and FJ Richardson: Melbourne).

Taylor, G.S. (1997) Effect of plant compounds on the population dynamics of the lerp insect, *Cardiaspina albitextura* Taylor (Psylloidea: Spondyliaspididae) on eucalypts. In: *Ecology and evolution of plant-feeding insects in natural and man-made environments* (ed. A. Raman). pp. 37–57. (International Scientific Publications: New Delhi).

Tippett, J.T., Hill, T.C. & Shearer, B.L. (1985) Resistance of *Eucalyptus* spp. to invasion by *Phytophthora cinnamomi. Australian Journal of Botany* 33**:** 409–418.

Wardell-Johnson, G. Stone, C., Recher, H. and Lynch, A.J.J. (2005) A review of eucalypt dieback associated with bell miner habitat in south-eastern Australia. *Australian Forestry* 68: 231–236.

Waring, R.H. (1991) Responses of evergreen trees to multiple stresses. In: *Response of plants to multiple stresses* (eds. H.A. Mooney, W.E. Winner & E.J. Pell). pp. 371–390. (Academic Press, Inc.: San Diego).

West, P.W. (1979) Rate of onset of regrowth dieback and its relation to summer drought in eucalypt forest of southern Tasmania. *Annuals of Applied Biology* 93: 337–350.

Weston, C.J. & Attiwill, P.M. (1990) Effect of fire and harvesting on nitrogen transformations and ionic mobility in soils of *Eucalyptus regnans* forests of south-eastern Australia. *Oecologia* 83: 20–26.

White, T.C.R. (1970) Some aspects of the life history, host selection, dispersal, and oviposition of adult *Cardiaspina densitexta* (Homoptera: Psyllidae). *Australian Journal of Zoology* 18: 105–117.

White, T.C.R. (1971) Lerps insects (Homoptera, Psyllidae) on red gum (*E. camaldulensis*) in South Australia. *South Australian Naturalist* 46: 20–23.

White, T.C.R. (1986) Weather, Eucalyptus dieback in New England, and a general hypothesis of the cause of dieback. *Pacific Science* 40: 58–78.

Whitehead, D. & Beadle, C.L. (2004) Physiological regulation of productivity and water use in *Eucalyptus*. *Forest Ecology and Management* 193: 113–140.

Woodburn, T.L. & Lewis, E.E. (1973) A comparative histological study of the effects of feeding by nymphs of four psyllid species on the leaves of eucalypts. *Journal of Australian Entomological Society* 12: 134–138.

York, A. (1999) Long-term effects of frequent low-intensity burning on the abundance of litter-dwelling invertebrates in coastal blackbutt forests of southeastern Australia. *Journal of Insect Conservation* 3: 191–199.

Manuscript accepted 14 March 2006

Quantifying the abundance of four large epiphytic fern species in remnant complex notophyll vine forest on the Atherton Tableland, north Queensland, Australia

Jason Cummings[1,2], *Michelle Martin*[1] *and Anne Rogers*[1]

[1]School for Field Studies, PO Box 141, Yungaburra QLD 4884
[2]Present address GHD Pty Ltd, Belconnen ACT 2617 email:jason.cummings@ghd.com.au

Abstract: Epiphytes are generally considered rare in complex forests on the western edge of the Atherton Tablelands, north Queensland. This assertion is based on comparisons with wetter forests in the Wet Tropics bioregion, but is of limited use in restoration projects where targets need to be quantified. We quantified 'rarity' for a subset of the epiphyte community in one of the largest remaining patches of Type 5b rainforest at Wongabel State Forest (17°18' S, 145°28' E). The abundance of large individuals of the epiphytic fern species *Asplenium australasicum*, *Drynaria rigidula*, *Platycerium bifurcatum*, and *Platycerium superbum* were recorded from 100 identified mid-storey or canopy trees. Epiphytes were less rare than the canopy trees sampled, averaging 1.7 individuals per tree. A clumped distribution was suggested with large epiphytes only occurring on 57 of the 100 trees. As tree size increased so did the number of individuals and species of large epiphytes recorded; only trees taller than 20 m yielded more than one epiphyte. Trees from the Meliaceae and Rutaceae hosted the most epiphytes, but host tree specificity patterns were not conclusive. Techniques for including epiphytes in restoration planning and projects are considered, and a quantified restoration target for epiphyte communities in Type 5b plantings is outlined.

***Cunninghamia* (2006) 9(4): 521–527**

Introduction

Historical land clearing associated with timber-getting and agriculture has lead to significant fragmentation of the rainforests of tropical North Queensland (Goosem et al. 1999). Since the establishment of the Wet Tropics World Heritage Area in 1988, the economic base for many local communities has gradually changed from forestry to tourism. Given the high biodiversity values of the rainforests in tropical North Queensland, and the creation of an extensive reserve system, conservation efforts for these rainforests have increasingly included restoration of forest linkages across the fragmented landscape (WTMA 2004). Rainforest communities on the Atherton Tablelands of tropical North Queensland are some of the most highly fragmented, and are at further risk from predicted climate changes (Hilbert et al. 2001). Therefore, the imperative to restore these communities, and linkages between them, is paramount (Catterall et al. 2004).

'Type 5b' forest, or complex notophyll vine forest, was first mapped by Tracey and Webb (1975) and has the notoriety of recently being scheduled as one of Australia's first *critically endangered* ecosystems (QLD EPA Regional Ecosystem 7.8.3, DEH 2005). The majority of this forest type occurs on nutrient rich basalt soils across a variety of elevations associated with the Atherton Tablelands in far North Queensland. Land clearing has resulted in the loss of at least 90 % of its original area. The reduction in size and connectivity between patches has been recognised as a major conservation issue for this forest type (DEH 2005), and stimulated the restoration of patches and corridors on the Atherton Tablelands.

Since the mapping and description of 'Type 5b' rainforest (Tracey & Webb 1975, Tracey 1987), significant efforts have been made to save this endangered forest type through reservation and ecological restoration. At the site scale, creation of new patches of rainforest on private and government land have relied primarily on planting and weed control (Goosem & Tucker 1995; Tucker et al. 2004) with many now achieving canopy closure (Kanowski et al. 2003). At this stage of restoration, it is appropriate to consider whether the plantings are on a trajectory towards becoming patches of Type 5b rainforest.

Epiphytes are plants rooting on the surface of tree trunks or branches without harming the host tree (Benzing 2004). Epiphytes contribute to species diversity, primary productivity, biomass, litter fall, water retention, and provide substrate for nitrogen fixing bacteria (Benzing 1998, Munoz et al. 2003). Epiphytes also provide important resources including forage sites and shelter to many canopy animals such as birds (Cruz-Angon & Greenberg 2005), pythons (Freeman et al. 2005), and invertebrates (Ellwood et al. 2002). From a Wet Tropics perspective, epiphytes contribute a substantial component of 'complexity' to 'complex' forests (Tracey 1987) and have been used as an indicator of structural complexity in comparing local plantations, ecological restoration plots and mesophyll and notophyll forests (Wardell-Johnson et al. 2005). Ecological restoration projects on the Atherton Tablelands have now been undertaken for over 20 years, focusing on the re-planting of forest communities in land that was previously used for agriculture (Goosem & Tucker 1995; Catterall et al. 2004). With the successful establishment of tree cover (Kanowski et al. 2003), the question of how to re-introduce those elements of rainforest ecosystems that make them 'rainforest' (e.g. lianes, large-leaved herbs, palms, and epiphytes) can be examined. Restoration of forest types that are defined by the presence of epiphytes (amongst other life forms), will ultimately necessarily involve restoration of epiphyte communities. Establishment of epiphyte communities will enhance energy capture, moisture capture and retention, and biotic community diversity in restoration plantings, continuing the process of returning agricultural pasture to a complex forest.

Despite their inherent importance, there has been no systematic survey of epiphyte populations across the Wet Tropics. The comparison of restoration plots with reference forest communities has been recommended to monitor progress and assess success (Kanowski et al. 2003; Catterall et al. 2004; Wardell-Johnson et al. 2005), to do this we need to quantify the various structural elements in complex forests to provide benchmarks for restoration plots. We have initiated a program to begin to determine ways of re-introducing epiphytes to rainforest plantings, but we have no knowledge of appropriate restoration targets (e.g. biomass of epiphytes per m^3, number of species per tree etc.) for plantings. If the goal is to restore complex forest communities, restoration success cannot be demonstrated without such targets (Lake 2001).

Several large epiphyte species occur in Type 5b rainforests (Plate 1), including (but not limited to) *Asplenium australasicum* (Bird's Nest Fern), *Drynaria rigidula* (Basket Fern), *Platycerium bifurcatum* (Elkhorn Fern), and

Table 1. Species richness and abundance of epiphytes for tree families in complex notophyll vine forest in Wongabel State Forest, north Queensland. Families below the line had fewer than 5 trees sampled.

Tree family	Number of trees sampled	Number of epiphyte species recorded	Epiphyte species richness per tree (means +/- se)	Epiphyte abundance per tree (means +/- se)
Meliaceae	14	8	1.00 (0.23)	3.71 (1.05)
Rutaceae	13	7	1.08 (0.35)	2.46 (0.81)
Lauraceae	11	7	0.82 (0.23)	1.55 (0.47)
Euphorbiaceae	6	2	1.00 (0.37)	1.50 (0.56)
Monimiaceae	6	3	1.00 (0.45)	1.83 (0.79)
Sapindaceae	6	3	0.50 (0.22)	0.67 (0.33)
Sterculiaceae	5	4	0.80 (0.37)	1.20 (0.49)
Alangiaceae	3	1	0.33 (0.33)	0.33 (0.33)
Boraginaceae	3	2	0.33 (0.33)	0.33 (0.33)
Myrtaceae	3	3	0.00 (0.00)	0.00 (0.00)
Sapotaceae	3	3	0.33 (0.33)	0.67 (0.67)
Verbenaceae	3	2	0.33 (0.33)	0.67 (0.67)
Anacardiaceae	2	2	1.50 (0.50)	3.50 (1.50)
Apocynaceae	2	1	1.00 (0.00)	1.00 (0.00)
Elaeocarpaceae	2	2	0.50 (0.50)	2.00 (2.00)
Fabaceae	2	1	1.00 (0.00)	1.50 (0.50)
Moraceae	2	2	1.50 (1.50)	2.00 (2.00)
Myristicaceae	2	1	0.50 (0.50)	1.50 (1.50)
Nyctaginaceae	2	1	1.00 (0.00)	1.00 (0.00)
Proteaceae	2	1	1.00 (1.00)	1.00 (1.00)
Urticaceae	2	2	1.00 (0.00)	1.00 (0.00)
Araliaceae	1	1	0.00 (NA)	0.00 (NA)
Ebenaceae	1	1	1.00 (NA)	1.00 (NA)
Flacourtiaceae	1	1	0.00 (NA)	0.00 (NA)
Surianaceae	1	1	0.00 (NA)	0.00 (NA)
Thymelaeaceae	1	1	0.00 (NA)	0.00 (NA)
Ulmaceae	1	1	0.00 (NA)	0.00 (NA)

Platycerium superbum (Staghorn Fern). Two of these species (or their congeners) have been noted for their functional significance; *Asplenium nidus* has been implicated in mediating forest climate (Palmer & Stork 2005) and hosting invertebrate communities (Ellwood et al. 2002), whilst *Drynaria rigidula* has been noted as providing a basking habitat for large pythons (Freeman et al. 2005; pers. obs.). Despite differences in shape, the contribution each of these species makes to canopy soil organic matter (*sensu* Nadkarni et al. 2002) via their nest building growth processes (Jones & Clemesha 1976), means each is likely to contribute to maintaining forest humidity. Further, each of these species also contributes in their own right to forest structure and biodiversity. The aim of this study was to survey large epiphytes in a patch of Type 5b forest to: (1) document their abundance within a mature Type 5b forest stand; (2) highlight potential affinities between epiphyte species and host taxa; and (3) recommend quantified targets for epiphyte establishment in developing Type 5b restoration plantings on the Atherton Tablelands.

Methods

Wongabel State Forest, located on the western edge of the Atherton Tablelands (17°18' S, 145°28' E) in the wet tropics region of north Queensland, is a reserve of approximately 600 ha containing Type 5b rainforest (complex notophyll vine forest; Webb & Tracey 1975). The Type 5b forest at Wongabel occurs on basalt soil, and has a multi-layered canopy ranging in height from 25 to 45 m, and a distinct shrub layer (Webb & Tracey 1975).

In March 2005 100 trees whose crowns reached the canopy or were in the mid-storey were surveyed. Trees sampled were

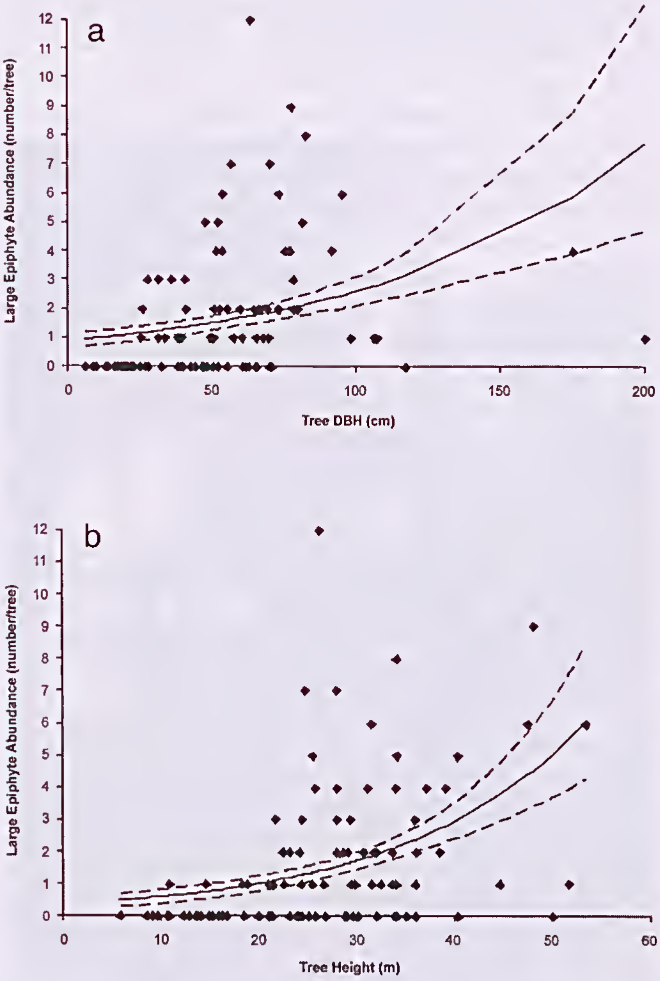


Fig. 1. The relationship between large epiphyte abundance and a) tree dbh, and b) tree height. Diamonds are observed values, the solid line is the predicted mean and dashed lines are lower and upper 95 % confidence limits.

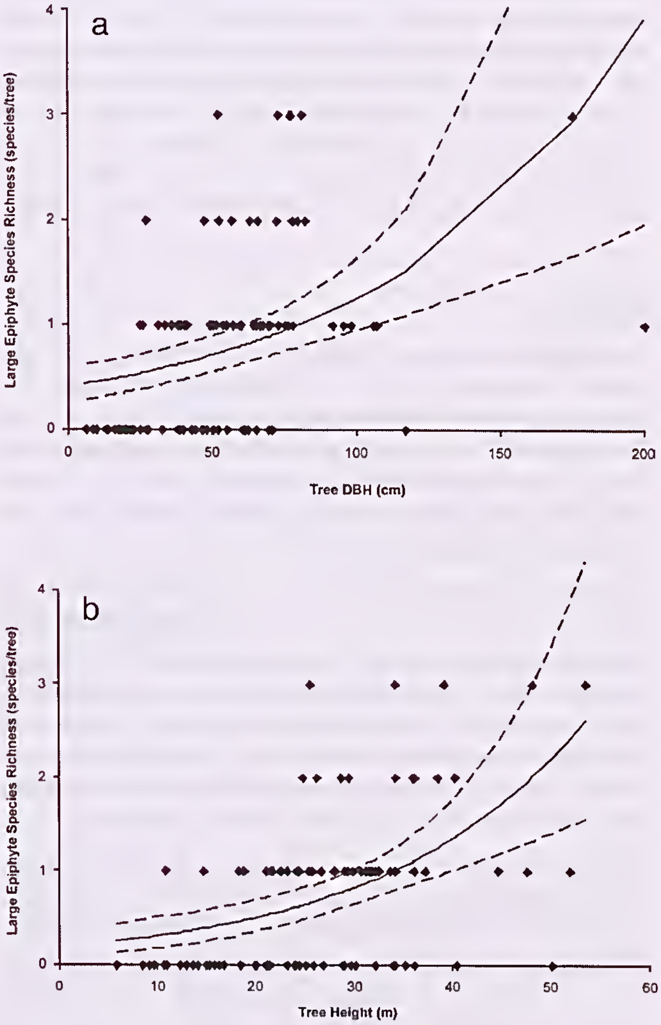


Fig. 2. The relationship between large epiphyte species richness and a) tree dbh, and b) tree height. Diamonds are observed values, the solid line is the predicted mean and dashed lines are lower and upper 95 % confidence limits.

all within 20 m of a trail through the forest and identified using a botanical guide developed specifically for this trail (Queensland Department of Forestry 1987). The presence and abundance of *Asplenium australasicum* (Aspleniaceae, Bird's Nest Fern), *Drynaria rigidula* (Polypodiaceae, Basket Fern), *Platycerium bifurcatum* (Polypodiaceae, Elkhorn Fern), and *Platycerium superbum* (Polypodiaceae, Staghorn Fern) were recorded (Andrews 1990). These species were selected as they can be readily distinguished from the ground once their reproductive fronds have developed, and are large and therefore potentially functionally significant (e.g. for moisture capture and forest humidity retention). To ensure accurate species identification from the ground using binoculars, only epiphytes with a basal diameter (the area of contact between the fern and the host tree) greater than about 10 cm were recorded. Host tree height and diameter at breast height (dbh) were recorded using a clinometer and diameter tape, respectively.

Poisson regressions using a log-link function were used to determine whether host-tree height or dbh influence the abundance and species richness of large epiphytes. Multiple regressions were not used as host tree dbh and height are not independent. The test of significance of the logistic regression models was the Wald statistic, which is tested against the Chi-square distribution (StatSoft 1999). All analyses were performed using the program STATISTICA (StatSoft, Oklahoma, USA).

Results

Large epiphytes occurred on 57 % of trees sampled, at an overall average of 1.7 (+/– 0.3) epiphytes per tree. The average abundance of large epiphytes on the 57 host trees was 2.9 (+/– 0.4). No trees sampled had all four species surveyed, with an overall average species richness of 0.8 (+/– 0.1). For host trees only, epiphyte species richness increased to 1.4 (+/– 0.1) epiphyte species per tree.

Asplenium australasicum was the most frequent large epiphyte, with 113 individuals recorded on 46 of the 100 trees sampled. On host trees, *Asplenium australasicum* abundance averaged 2.5 (+/– 0.3) individuals per tree. Individuals of *Drynaria rigidula* were recorded 35 times on 20 host trees at an overall average abundance of 1.1 (+/– 0.3) individuals per host tree. Only 16 *Platycerium superbum* and 3 *Platycerium bifurcatum* were recorded on the 100 trees sampled.

Both host tree height (Wald statistic = 52.9, df = 1, $p < 0.001$) and dbh (Wald statistic = 37.5, df = 1, $p < 0.001$) contributed to variation in epiphyte abundance. As tree height and dbh increased, the number of large epiphytes also increased (Fig. 1). Total epiphyte abundance ranged from 0–1 in 'small trees' (< 20 m) to 0–12 in relatively 'large trees' (> 20 m). Similarly, host tree height (Wald statistic = 21.2, df = 1, $p < 0.001$) and dbh (Wald statistic = 20.3, df = 1, $p < 0.001$) contributed to the number of species of large epiphytes recorded. With increasing tree size, epiphyte species richness increased, within the 1–4 species range (Fig. 2).

Representatives of 27 families were sampled for epiphytes, with 7 families having 5 or more individuals sampled (Table 1). Host trees from the Meliaceae and Rutaceae, the most commonly sampled families, exhibited the greatest frequency of epiphyte abundance. The Sapindaceae yielded about 25 % of the epiphyte abundance compared to Meliaceae and Rutaceae with the Lauraceae, Euphorbiaceae and Monimiaceae intermediate. Species richness patterns with respect to host tree family were less evident, each of the aforementioned families, except the Sapindaceae, averaged around 1 species of large epiphyte per tree.

Discussion

Large epiphytes were, on average, as abundant as the trees in Wongabel State Forest at 1.7 individuals per tree and occurring on 57 % of all trees. There has been no estimate of epiphyte abundance in Australian tropical rainforests, although they have been estimated to contribute up to 10 % of native plant species richness in tropical forests and approximately 5 % in sub-tropical forests (Wardell-Johnson et al. 2005). In Brazilian rocky outcrops, an average of 9.5 vascular epiphytes per *Vellozia piresiana* (a small tree) was recorded, but this survey included a larger array of epiphyte species across size ranges (de Souza Werneck & Espirito-Santo 2002). Only 23 % of *Vellozia piresiana* did not host epiphytes. On tree ferns in Tasmanian closed forests, frequency of occurrence of *Asplenium bulbiferum* and *Microsorum pustulatum* (Polypodiaceae) ranged from 18–26 % and 10–18 %, respectively (Roberts et al. 2003). Despite the difficulties in comparisons, it is likely epiphyte abundance in Type 5b rainforest is lower than tropical forests elsewhere in the Tropics but greater than southern Australian forests.

Asplenium australasicum was the most abundant large epiphyte species in this forest, occurring on nearly half of the trees sampled. *Asplenium* species have been noted for their abundance in tropical forests throughout the world (Ellwood & Foster 2004). *Asplenium* species often contain significant invertebrate communities (Ellwood et al. 2002) and their rosette shape captures and retains moisture. The abundance of *Asplenium australasicum* in this Type 5b rainforest patch seems contradictory to the assertion that epiphytes are rare in this forest type (Tracey 1987), and ignoring them in restoration efforts may reduce the functional complexity of restoration plantings. When compared to wetter forest types in this region, *Asplenium australasicum* may be relatively less abundant in Type 5b forest, but until its relative abundance in different forest types is quantified, a degree of caution should be taken when considering management, and especially restoration, of these forests.

Taken together, the other three epiphyte species surveyed, summed to less than half of the number of large epiphytes recorded. Comparisons of the recorded abundances of *Drynaria rigidula*, *Platycerium bifurcatum* and *Platycerium superbum* with other locations are difficult, with no information on abundances available. Interestingly, *Drynaria rigidula* is noted for its occurrence in drier, more open forests in Queensland (Andrews 1990) and was not listed as an epiphyte that occurred in this forest type when it was described (Tracey 1987). Given that *Platycerium bifurcatum* was listed for Type 5b rainforest (Tracey 1987), and that in this survey it occurred 10-times less frequently than *Drynaria rigidula*, a change in epiphyte community composition may have occurred in the last 20 years. Given the potential for epiphyte communities to be used as climate change indicators (Benzing 1998), further work is required to test this hypothesis across remnants of Type 5b rainforest.

Tree size contributed to the number and species richness of large epiphytes in Type 5b rainforest. Larger trees supported more epiphytic bromeliads in Costa Rican tree plantations (Merwin et al. 2003). For three host tree species, *Polypodium polypodioides* (Polypodiaceae) abundance increased with tree dbh in American sub-tropical forest (Callaway et al. 2002). Tree size relates to several factors that contribute to epiphyte establishment and growth. Larger trees are likely, on average, to be older, allowing more time to capture spores. Taller trees provide better access for epiphytes to light, whilst large trees, both in terms of height in canopy and surface area available, likely capture more water than small trees, an essential determinant of epiphyte distribution (Benzing 2004). The increase in abundance of epiphytes with tree size in this Type 5b patch is in accordance with findings elsewhere. For restoration of Type 5b forest to be considered successful, large epiphytes should occur on approximately half of the trees in restoration plots once those trees reach a height greater than 20 m.

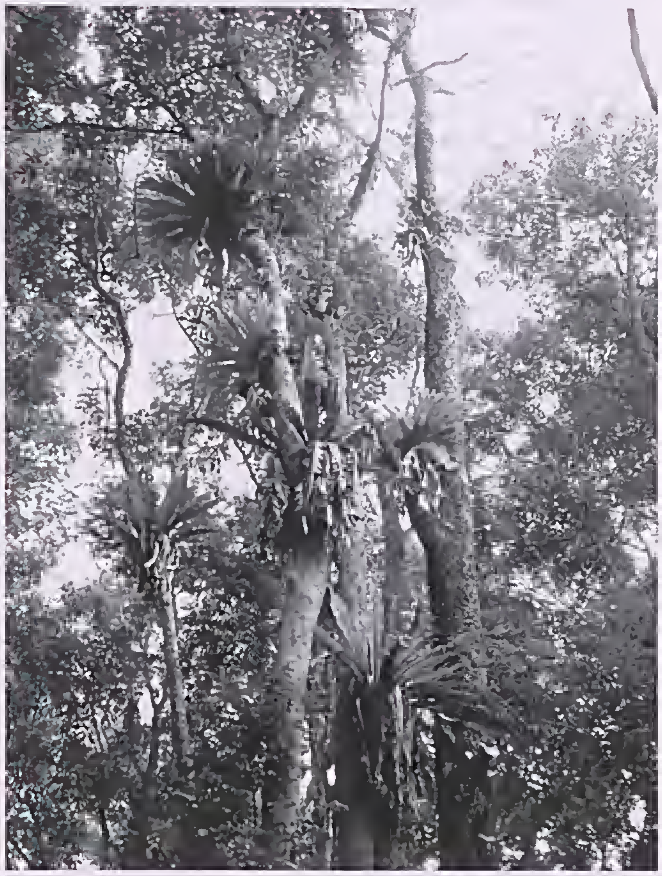


Fig. 3. An example of *Platycerium superbum* and *Asplenium australasicum* occurring in Wongabel State Forest, where epiphytes are considered 'rare' compared to other forest types

The Meliaceae and Rutaceae displayed the greatest abundance of large epiphytes, whilst the species richness was relatively even amongst host-tree families. Host tree specificity explains the distribution of some epiphytic taxa (e.g. Nieder et al. 2000; Callaway et al. 2002; Moran et al. 2003) but not others (e.g. Zimmerman & Olmsted 1992). The evidence for host tree specificity in the case of epiphyte species surveyed here is inconclusive but warrants further investigation. From a pragmatic perspective, introduction of epiphytes into restoration plantings should initially focus on host trees from the Meliaceae and Rutaceae families.

Management Implications

For a subset of the epiphyte community, the assertion that epiphytes are rare in Type 5b forests (Tracey 1987; DEH 2005) has now been quantified. On average, large epiphytes are only as rare as the trees that comprise this forest type. We have observed members of the genera *Pyrrosia*, *Belvisia*, *Antrophyum* and *Dendrobium* in this forest patch, undoubtedly if these smaller epiphytes were included in the survey, epiphytes would be more abundant per unit area than host trees. Semantics aside, epiphytes warrant consideration in planning restoration of these complex forest communities and this study allows the development of quantified goals for their establishment.

A goal of establishing large epiphytes on approximately half of the trees in a restoration planting seems reasonable given their observed abundances in this forest. Under ideal circumstances, conditions favourable to epiphyte establishment will be created and dispersal from adjacent remnants should occur (Kanowski et al. 2003; Catterall et al. 2004; Wardell-Johnson et al. 2005). To promote and accelerate restoration of structurally complex forests, epiphytes should be considered for early reintroduction to restoration plantings, particularly given their functional significance. *Asplenium australasicum* and *Drynaria rigidula* should provide an initial focus for restoration efforts once canopy closure has been achieved in Type 5b restoration plantings. Individuals could initially be sourced from local tree falls or land being cleared, but ideally propagation techniques from spores should be considered (e.g. Bourne 1994).

Ecosystem function will likely be enhanced by placement of epiphytes into restoration plantings; habitat complexity will be increased and moisture and energy capture and retention will be enhanced. Further, with epiphytes incorporated into a restoration planting, the elusive claim of 'restoration success', with respect to establishing complex forest communities, will be one step closer.

Although structural complexity has been considered at a broad scale across re-forestation types (Kanowski et al. 2003; Catterall et al. 2004), there has been little consideration of establishing complexity within restoration plantings. In young restoration plantings (6–22 years old), epiphyte frequency has been recorded at approximately 17 % of nearby intact forest (Kanowski et al. 2003) and epiphyte species have been noted to colonise plantations greater than 50 years of age (Keenan et al. 1997). Given the functional benefits that epiphytes may provide to a young restoration planting, their accelerated inclusion into plantings should be considered. Under circumstances where restoration plantings are spatially isolated and thus recruitment may be limited (Tucker & Murphy 1997), epiphytes may need to manually reintroduced to move the planting towards a complex forest community.

Acknowledgements

Tim Curran and an anonymous reviewer provided valuable comments on a draft of this manuscript. The work was fully supported by the School for Field Studies, and represents contribution 05/JC01 to the Centre for Rainforest Studies' 5-year Research Plan.

References

Andrews, S.B. (1990) *Ferns of Queensland*. (Queensland Dept of Primary Industries: Brisbane).

Benzing, D.H. (1998) Vulnerabilities of tropical forests to climate change: the significance of resident epiphytes. *Climatic Change* 39: 519–540.

Benzing, D.H. (2004) Vascular epiphytes. Pp. 175–211 in Lowman, M.D. & Rinker, H.B. (eds.), *Forest Canopies* (Elsevier Academic Press: Sydney).

Bourne, R.A. (1994) The development of a program of commercial production of staghorns from plant tissue culture. *Combined Proceedings International Plant Propagators' Society* 44: 90–93.

Callaway, R.M., Reinhart, K.O., Moore, G.W., Moore, D.J. & Pennings, S.C. (2002) Epiphyte host preferences and host traits: mechanisms for species-specific interactions. *Oecologia* 132: 221–230.

Catterall, C.P., Kanowski, J., Wardell-Johnson, G., Proctor, H., Reis, T., Harrison, D. & Tucker, N.I.J. (2004) Quantifying the biodiversity values of reforestation: perspectives, design issues and outcomes in Australian rainforest landscapes. Pp. 359–393 in Lunney, D. (ed.), *Conservation of Australia's Forest Fauna* (Royal Zoological Society of NSW, Sydney).

Cruz-Angon, A. & Greenberg, R. (2005) Are epiphytes important for birds in coffee plantations? An experimental assessment. *Journal of Applied Ecology* 42: 150–159.

de Souza Werneck, M. & do Espirito-Santo, M.M. (2002) Species diversity and abundance of vascular epiphytes on *Vellozia piresiana* in Brazil. *Biotropica* 34: 51–57.

DEH (2005) Mabi Forest - Advice to the Minister for the Environment and Heritage from the Threatened Species Scientific Committee (TSSC) on Amendments to the List of Ecological Communities under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Dept of Environment and Heritage: Canberra).

Ellwood, M.D.F. & Foster, W.A. (2004) Doubling the estimate of invertebrate biomass in a rainforest canopy. *Nature* 429: 549–551.

Ellwood, M.D.F., Jones, D.F. & Foster, W.A. (2002) Canopy ferns in lowland dipterocarp forest support a prolific abundance of ants, termites, and other invertebrates. *Biotropica* 34: 575–583.

Freeman, A.B., Freeman, A.N.D. & Krockenberger, A. (2005) Predators on the prowl: how does Australia's largest snake survive in a fragmented landscape? Poster presentation. (Joint Meeting of Ichthyologists and Herpetologists, Tampa, Florida).

Goosem, S., Morgan, G. & Kemp, J.E. (1999) Wet Tropics. Chapter 7 in P.S. Sattler & R.D. Williams (eds), *The Conservation Status of Queensland's Regional Ecosystems*. (Environmental Protection Agency: Brisbane).

Goosem, S. & Tucker, N.I.J. (1995) *Repairing the rainforest: theory and practice of rainforest re-establishment in north Queensland's Wet Tropics* (Wet Tropics Management Authority: Cairns).

Hilbert, D.W., Ostendorf, B. & Hopkins, M.S. (2001) Sensitivity of tropical forests to climate change in the humid tropics of north Queensland. *Austral Ecology* 26: 590–603.

Jones, D.L. & Clemesha, S.C. (1976) Australian Ferns and Fern Allies. (A.H. & A.W Reed, Sydney).

Kanowski, J., Catterall, C.P., Wardell-Johnson, G.W., Proctor, H. & Reis, T. (2003) Development of forest structure on cleared rainforest land in eastern Australia under different styles of reforestation. *Forest Ecology and Management* 183: 265–280.

Keenan, R.J., Lamb, D., Woldring, O., Irvine, T. & Jensen, R. (1997) Restoration of plant biodiversity beneath tropical tree plantations in Northern Australia. *Forest Ecology and Management* 99: 117–131.

Lake, P.S. (2001) On the maturing of restoration: linking ecological research and restoration. *Ecological Management and Restoration* 2: 110–115.

Merwin, M.C., Rentmeester, S.A. & Nadkarni, N.M. (2003) The influence of host tree species on the distribution of epiphytic bromeliads in experimental monospecific plantations, La Selva, Costa Rica. *Biotropica* 35: 37–47.

Moran, R.C., Klimas, S. & Carlsen, M. (2003) Low-trunk epiphytic ferns on tree ferns versus angiosperms in Costa Rica. *Biotropica* 35: 48–56.

Munoz, A.A., Chacon, P., Perez, F., Barnert, E.S., & Armesto, J.J. (2003) Diversity and host tree preferences of vascular epiphytes and vines in a temperate rainforest in Southern Chile. *Australian Journal of Botany* 51: 381–391.

Nadkarni, N.M., Schaefer, D., Matelson, T.J., & Solano, R. (2002) Comparison of arboreal and terrestrial soil characteristics in a lower montane forest, Monteverde, Costa Rica. *Pedobiologia* 46: 24–33.

Nieder, J., Engwald, S., Klawun, M. & Barthlott, W. (2000) Spatial distribution of vascular epiphytes (including hemiepiphytes) in a lowland Amazonian rain forest (Surumoni Crane Plot) of southern Venezuala. *Biotropica* 32: 385–396.

Palmer, N. & Stork, N. (2005) *The Australian Canopy Crane 1999–2005: supporting world class canopy research.* (Rainforest CRC: Cairns, Australia).

Queensland Department of Forestry (1987) *Visitor information: Wongabel botanical walk.* (Queensland Dept of Forestry: Atherton District).

Roberts, N.R., Dalton, P.J., & Jordan, G.J. (2003) A species list for the bryophytes and ferns occurring as epiphytes on Tasmanian tree ferns. *Hikobia* 14: 25–31.

StatSoft (1999) STATISTICA for Windows. (StatSoft: Oklahoma).

Tracey, J.G. (1987) *The vegetation of the humid tropical region of north Queensland.* (CSIRO: Melbourne).

Tracey, J.G. & Webb, L.J. (1975) *Vegetation of the humid tropical region of north Queensland* (CSIRO: Brisbane).

Tucker, N.I.J. & Murphy, T.M. (1997) The effects of ecological rehabilitation on vegetation recruitment: some observations from the Wet Tropics of north Queensland. *Forest Ecology and Management* 99: 133–152.

Tucker, N.I.J., Wardell-Johnson, G., Catterall, C.P., & Kanowski, J. (2004) Agroforestry and biodiversity: improving conservation outcomes in tropical northeastern Australia. Pp. 431–452 in Schroth, G., da Fonseca, G.A.B., Harvey, C.A., Gascon, C., Vasconcelos, H.L. & Izac, A.N. (eds.), *Agroforestry and Biodiversity Conservation in Tropical Landscapes* (Island Press: Washington DC).

Wardell-Johnson, G., Kanowski, J., Catterall, C.P., McKenna, S., Piper, S. & Lamb, D. (2005) Rainforest timber plantations and the restoration of plant biodiversity in tropical and subtropical Australia. Pp. 162–182 in Erskine, P.D., Lamb, D. & Bristow, M. (eds.), *Reforestation in the Tropics and Subtropics of Australia* (Rural Industries Research and Development Corporation, Canberra, and the Rainforest CRC: Cairns).

WTMA (2004) Wet Tropics Conservation Strategy (2004) (Wet Tropics Management Authority and Queensland Parks and Wildlife Services: Cairns).

Zimmerman, J.K. & Olmstead, I.C. (1992) Host tree utilization by vascular epiphytes in a seasonally inundated forest (Tintal) in Mexico. *Biotropica* 24: 402–407.

Manuscript accepted 14 March 2006

The effect of population structure, plant size, herbivory and reproductive potential on effective population size in the temperate epiphytic orchid, *Sarcochilus australis*

Raymond L. Tremblay

Royal Botanic Gardens Melbourne, Private Bag 2000, Birdwood Ave. South Yarra, Victoria 3141, AUSTRALIA.
For correspondence: University of Puerto Rico - Humacao, 100 carr. 908, Department of Biology, Humacao, Puerto Rico, 00791, USA.
raymond@hpcf.upr.edu.

Abstract: Distribution of plant size and reproductive success is investigated in the temperate epiphytic orchid *Sarcochilus australis* (Lindl.) Rchb. f. at Kinglake National Park, Victoria, in south-eastern Australia, and applied to estimating the effective population size. Plant size distribution (leaf number, length of longest leaf and number of flowers) was not normally distributed. Most individuals were vegetative and it is estimated that more than half of all individuals are too small to flower, however exceptionally large individuals even though rare are able to have more than one active inflorescence. Flowering probability is plant size dependent and follows a sigmoid curve. The minimum observed leaf size of a flowering individual was 26 mm, however these small individuals have a low probability of flowering (<30%), while large plants (> 80 mm) have a much higher probability of flowering (90%). The effective population size (Ne) of the Kinglake population of *Sarcochilus australis* was estimated from the distribution of flower production, and shown to be small (Ne = 10–19%) and comparatively similar to some of the other published estimates of effective populations size in orchids. From this basic survey of size distribution in *Sarcochilus australis* it is predicted that genetic diversity is low.

***Cunninghamia* (2006) 9(4): 529–535**

Introduction

Plant population structure such as the distribution of plant size, and distribution of reproductive effort and success has important evolutionary and conservation implications. For example, plant size distribution has frequently been shown to effect survivorship and reproduction (Harper 1977, Wessilingh et al. 1997) and can be related to inter- and intra- specific competition (Harper 1977, Jack, 1971). In many plant species a minimum size is required to produce flowers while size and growth directly influence the size of the floral display (Pino et al., 2002; Metcalf et al., 2003). The size of floral display is frequently positively correlated with reproductive success either through increase male success (pollen removal) or female success (fruit production; Wesselingh et al., 1997; Pino et al., 2002; Metcalf et al., 2003). Since plant size affects reproductive output by influencing flower production (Harper 1977) and variation in plant size influences variation in reproductive success, reproductive effort ultimately influences effective population size through fruit set and progeny recruitment (Tremblay & Ackerman 2001).

The assumption of size influencing reproductive output is well documented, for example in the tree *Lindera erythrocarpa* seed production was highest in the largest individuals (> 28 cm dbh), which produced twice as many seeds as smaller trees (= 20 cm dbh; 7.7 x 10^4 and 4.2 x 10^4 seeds, respectively, Hirayama et al., 2004). This pattern is found in many species of angiosperms (Herrera 1991) including gymnosperms (Enright & Ogden 1979). Knowledge of plant size distribution and its relationship with reproductive potential can allow estimates of effective population size (Kimura & Crow 1963, Heywood 1986, Tremblay & Ackerman 2001) which is directly related to the likelihood of evolution by natural selection and genetic drift.

The relationship between genetic drift (random changes in genetic or morphological variation among generations) and selection, and their relative role in evolution depends on the effective population size (Ne), the number of effective breeding adults in a generation (Wright 1931, 1939, 1968). The smaller the Ne, the higher the probability that loss or fixation of alleles in the population will be caused by genetic drift and the higher the selection coefficients need be for natural selection to be important. When effective population sizes are below 50, drift is expected to be strong (Wright 1968; Franklin 1980).

Consequently, the relative contribution of progeny to the next generation has evolutionary and conservation implications. Do most individuals leave an equal amount of progeny or are some individuals more effective at leaving progeny? It is common that later stage individuals usually have a higher survival probability and reproductive success (Øien & Moen 2002, Pino et al., 2002) and consequently the distribution of size will influence the effective population size.

In this study five questions are evaluated for the temperate orchid *Sarcochilus australis* (Lindl) Rchb.f. 1) What is the plant size distribution as measured by the number of leaves, the length of the longest leaf and the number of flowers and are these variables normally distributed? 2) Which of the two size variable (leaf length or leaf number) a better predictor of flower production? 3) What is the probability of plants flowering based on leaf length? 4) How common and what impact is the effect of herbivores on floral production? 5) Ultimately, considering the variation in flower display what is the most likely estimate of effective population size?

Methods

Model species and sampling strategy

Sarcochilus australis is a twig epiphyte on a variety of host trees in wetter, cooler parts of eastern Australia, from Tasmania to Queensland (Backhouse & Jeanes 1995; Bishop 1996). I sampled all observed plants along a more-or-less random walk on the slopes of a small creek dominated by ferns in the understorey at one site at Kinglake National Park, Victoria. The survey included only plants that were reachable, though few observed plants were observed beyond reach.

For each plant the number of leaves was counted, the length of the longest leaf was measured (mm), and number of inflorescences and flowers per inflorescence were counted. The presence of herbivory on flowers was noted when the tip of the inflorescence was damaged. The total number of flowers produced by a plant was calculated as the sum of flowers from all inflorescences.

Statistical analysis and plant size distribution

Initial data exploration involved graphing the frequency distribution of plant size (number of leaves and length of longest leaf) and number of flowers per plant to determine the pattern and evaluate if the variables studied follow a normal distribution. Test of normal distribution was performed with the "Shapiro-Wilk W test for normality" (Shapiro & Wilk 1965). The relationship between leaf length and leaf number with flower production was evaluated with multivariate linear regression analysis. The variable that explained most of the variation was then used exclusively to evaluate the likelihood of plants flowering. The likelihood of flowering was evaluated using logistic regression, the length of the longest leaf as the predictive variable and the presence (or absence) of an inflorescence as the response variable. All statistics (excluding effective population size (Ne) calculations) were performed with the statistical package JMP 5.1.2 (SAS Institute Inc., Cary, N.C., USA).

In all cases statistical analyses were performed on the square root of the number of leaves and number of flowers and the log of the length of the longest leaf to reduce heteroscedasticity. Tables and figures are shown with non-transformed data for ease of interpretation.

Estimating effective population size from variation in flower production.

The model "variance as a function of size distribution" (Kimura & Crow 1963) describes the effective population size as a function of the progeny distribution among individuals. The model assumes that size of an individual is directly related to the number of progeny produced and this is largely supported with empirical and theoretical analyses (Metcalf et al., 2003). Flower production is usually highly correlated with fruit set and recruitment (Herrera 2004). Heywood (1986) reformulated the function considering the variance in terms of reproductive success or potential. Here I use the number and variance in flower production as a measure of reproductive potential. Because this model is most appropriate for species with non-overlapping generations or species with small variance in reproductive lifespan, it serves as a comparison for models developed for overlapping generations and also provides a general estimate when populations have a short lifespan with little or no overlapping generations, consequently a upper range of the effective population size if variance is reproductive success is high (Tremblay & Ackerman 2001).

The effective population size is estimated as ,

$$Ne = \frac{1}{(1 + F)(\frac{s_b^2}{\overline{X}_b^2}) + 1} * N$$

where b is the variable of interest (number of flowers), s^2 and $\overline{x}$ are the variance and the mean of the variable, F is the genetic estimate of inbreeding (F_{is}: ranging from 0 to 1), and N is the number of individuals sampled (Husband & Barrett 1992).

Results

Leaf number

The number of leaves per individual varied from one to eight and the population size distribution was skewed towards plants with fewer leaves, 2 to 5 leaves being the most common plant size (Fig. 1). The mean number of leaves per plant was 3.5 ± 0.12 (s.e.; n=154) and the median was 3. Leaf number was not normally distributed rather the distribution was skewed with more plants having fewer leaves (Shapiro-Wilk W Test for normality, $W = 0.9249$ $p < 0.0001$).

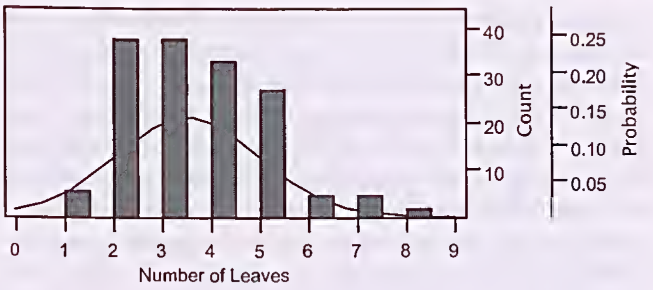


Fig. 1. Frequency and probability distribution of number of leaves per individual in 154 individuals of the temperate epiphyte *Sarcochilus australis* at Kinglake, Victoria.

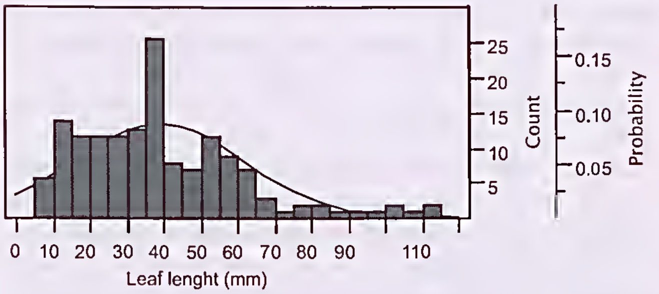


Fig. 2. Frequency and probability distribution of the length of the longest leaves of 154 individuals in the temperate epiphyte *Sarcochilus australis* at Kinglake, Victoria.

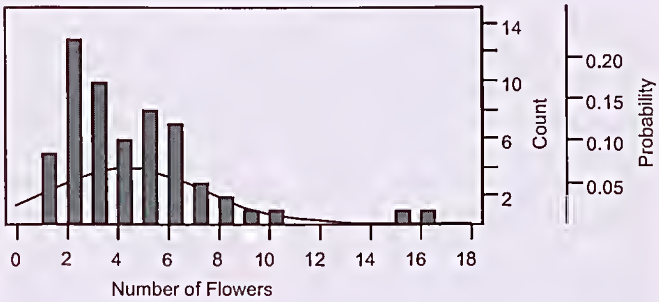


Fig. 3. Frequency and probability distribution of number of flowers per individual in 58 flowering individuals of the temperate epiphyte *Sarcochilus australis* at Kinglake, Victoria.

Leaf length.

The length of the longest leaf varied from 6 to 112 mm, with a mean of 38.9 mm (se = 1.8; median 35, n = 153), with 50% of the individuals lying between 22 and 53 mm (Fig. 2). The distribution of length of the longest leaf was significantly skewed (Shapiro-Wilk W Test for normality, $W = 0.9215$ $p < 0.0001$) with an excess of individuals with very long leaves.

Flower production

A total of 58 of the 154 plants had active inflorescences. The distribution of number of flowers per plant ranged from two to 16, the mean number of flowers was 4.4 for a total of 254 flowers (se = 0.40, n = 58, Fig 3). The distribution of flower production was significantly skewed (Shapiro-Wilk W Test for normality, $W = 0.8268$ $p < 0.0001$) towards fewer flowers, and few individuals had many flowers.

Plant size and flower production.

A multiple stepwise regression analysis of the total model including the length and number of leaves shows that flower production was positively correlated with the measures of plant size (multiple regression $F_{2,57} = 24.68$, $p < 0.0001$, $R^2_{adj} = 0.45$). However, leaf length explained more of the variation (log of leaf length, $F_{1,57} = 44.20$, $p < 0.0001$, $R^2_{adj} = 0.43$; Fig.4) compared to the number of leaves (sqrt of leaf number, $F_{1,57} = 20.7$, $p < 0.0001$, $R^2_{adj} = 0.26$). Leaf length and leaf number were correlated (Sqrt(N. leaves) = 0.4075274 + 0.9462978 Log(leaf), $F_{1,153} = 117.06$, $p < 0.0001$, $R^2_{adj} = 0.43$).

Minimal plant size for flowering.

The minimum leaf length of a flowering individual was 26 mm. Fifty individuals were smaller than 26 mm. Logistic regression of inflorescence presence and length of longest leaf suggested that small individuals had a low probability of producing inflorescences (logistic regression (log leaf length), n = 154, Chi Square = 68.97, $p < 0.0001$, R^2_{adj} (U) = 0.34). The probability of flowering was plant size dependent and followed a sigmoid curve. Plants with a 20 mm leaf length had approximately 10% probability of flowering, at 46 mm leaf length plants had a 50% probability of flowering, while a 90% probability of flowering was attained only when the longest leaf is larger then 73 mm (Fig. 5).

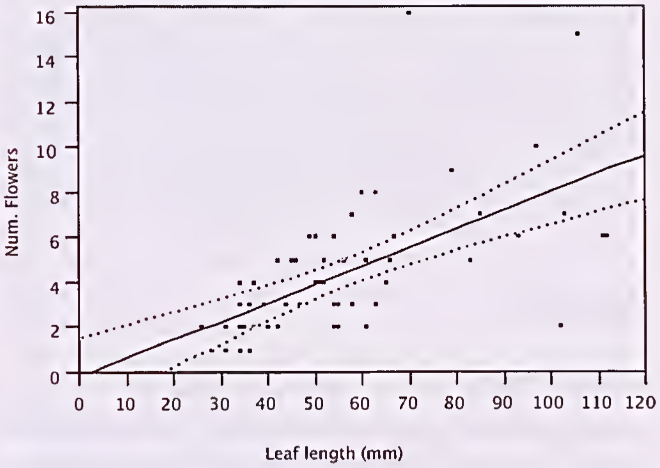


Fig. 4. Linear relationship (± standard error) between length of the longest leaf and the number of flowers born by *Sarcochilus australis* at Kinglake, Victoria. Sqrt(flowers) = –2.571755 + 2.6573918 Log(leaf).

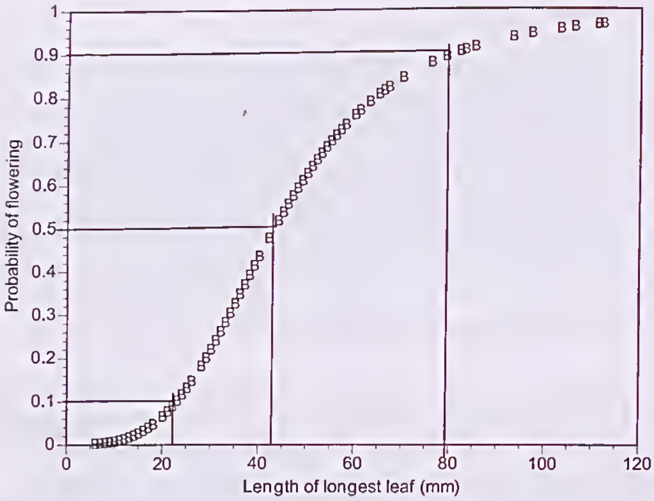


Fig. 5. Logistic regression of probability of flowering as influenced by the length of the longest leaf of *Sarcochilus australis*. The length of the longest leaf for a 10%, 50% and 90% flowering probability is shown.

Herbivory.

Evidence of herbivory on floral production was noted in 19 of 58 inflorescences. In none of the observed cases were all of the flowers on the inflorescence damaged; at least two flowers were present. The real effect of herbivory on these plants can be evaluated by comparing damaged to non-damaged flowering plants. Plants with evidence of herbivory had marginally fewer flowers (mean and s.e., 3.68 ± 0.44) than plants with no evidence of herbivory (mean and s.e., 4.72 ± 0.54). However, the effect of herbivory on plants was not significant (Sqrt of number of flowers, t-test, assuming unequal variance $t_{48.2} = 1.22$, $p = 0.23$).

Estimates of effective population size.

The variance in the number of flower per individual was 9.117 and the mean was 4.393. Consequently the range of Ne is from 10.3% of the standing reproductive individuals for a population that is completely inbred ($F_{is} = 1$) and up to 18.8% for a population that has little inbreeding ($F_{is} = 0$). Thus for *Sarcochilus australis*, the 58 flowering individuals are likely behaving as if 6 to 11 individuals.

Discussion

Size distribution

Leaf number, leaf length and flower production all exhibited skewed distributions with a high number of individuals in the smaller categories. Skewed distributions of vegetative characters are common in many plants (Harper, 1977). Plants size can be affected by plant density (Harper, 1977). *Sarcochilus australis* plants surveyed at the Kinglake site were most frequently alone or in groups of two or three, only on a couple of trees were a large number of plants present (>9), and on these hosts most of the plants were small. Were these plants recent recruits or are they competing for resources that ultimately affected their size? In general we know little about the effect of competition in orchids and population structure (Kull, 2002, Rivera-Gómez, et al., 2006). If density effects are present in orchids then this suggests that space and resources are limited (Kery et al., 2000). However, there is little evidence to suggest that space is the limiting factor to population dynamics of epiphytic orchids (Calvo & Horvitz 1990, Ackerman, et al., 1996), whereas some evidence of resources limitation on reproduction and growth patterns is known in field studies (Fernández et al., 2003). Most of the known effects of resource limitation have been observed as a consequence of the cost of reproduction among reproductive bouts (for an extensive review see Tremblay et al, 2005).

A predictor of flowering size

Leaf length is a better predictor of flower production then number of leaves and explains 43% of the variation. While adding leaf length and leaf number increases the resolution it only improves the resolution slightly ($R^2_{adj} = 0.45$), consequently, measuring the length of the longest leaf is sufficient for a quick survey of the reproductive potential in a population.

One third of individuals were smaller than the smallest individuals (leaf length of 26 mm) with an inflorescence. Considering plants equal and larger than 26 mm, 50 of the 108 (48.3%) did not flower. The likelihood of small individuals flowering with leaves below 30 mm is only about 20%, individuals with leaves over 40 mm have a 50% probability of flowering. All plants with leaves over 83 mm produced flowers (n=9). Production of multiple inflorescences was only noted three times in the survey, two of the largest individuals present in the survey produced two inflorescences (106 mm, 7 leaves; 112mm, 3 leaves) and one with three inflorescences (70 mm, 5 leaves). The conditions for a plant to produce multiple inflorescences is likely dependent on multiple variables including size and number of leaves, resource availability as well as choice location for maximising photosynthesis.

Plant size as a measure of reproductive potential and output is well known (Pino et al., 2002; Metcalf et al., 2003). In some species the relationship between plant size and fecundity measures can reach r^2 as high as 92% (for a review see Metcalf et al., 2003).

Resource limitations and growth.

In general the interaction of epiphytes and their physical and biological environment is still unknown. However, it has been documented that moss can dramatically affect water (Mägdefrau & Wutz 1951 in Proctor 1982, Pócs 1980) and nutrient availability (Coxson et al. 1992) but its interaction with epiphytic flora is unknown. The present of moss cover on trees in the Kinglake site was common and should be evaluated in relation to orchid presence and growth rates. Moss diversity does not appear to relate to epiphytic distribution (Tremblay et al. 1998). Otero et al. (2002) found that different fungi dramatically affect the germination and growth rates of seedlings of some orchid species. Different species of trees have diverse microfloras (Tremblay et al. 1998) and it is probable that this could influence population dynamics including recruitment (Bayman et. al. 2002; Willems et al. 2001), and consequently the presence, growth rate and density of orchids.

Herbivory

Herbivory could affect size distribution if the amount consumed is preferentially more on one of the stages then the others. In general, when herbivory has been noted in orchids the effect on survivorship appears to be minimal (Whigham & O'Neill, 1988; Primack & Hall 1990, Calvo 1990). Mammalian herbivory of young leaves of many terrestrial orchids is known in the Australian orchid flora, but little is know of its short and long-term effects (Coates, et al., 2006). Very little herbivory (insect damage) appears to be present in orchids in general. When herbivory was noted in *Sarcochilus australis* it was rare and limited to the tip of the inflorescence. In general the number of flowers that were damaged does not appear to be significant. Herbivory appears to be occurring prior to anthesis with all the bud being consumed. None of the open flowers had partial damage.

Effective population size.

How many individuals there are in a population and how they distribute the reproductive success among them has conservation and evolutionary consequences. It is generally held that, in theory, effective population sizes smaller than 50 are highly likely to go extinct and that genetic drift (lost of genetic and morphological diversity), is highly probable (Wright 1968, 1977). If by luck all *Sarcochilus australis* plants were sampled at Kinglake, this population has a Ne of 6–11 and is likely to experience genetic drift, which could lead to inbreeding depression and/or cladogenesis. However, the total population is unlikely to have been measured, as it is likely that many plants were missed in areas that were not surveyed. Unnoticed plants are likely higher up in the canopy and branch falls with orchids were found on the ground or hanging on to other living trees in the understorey, supporting the hypothesis that plants grow higher up in the canopy, as well as in the area surveyed. What is the true population size of *Sarcochilus australis* at Kinglake? For effective populations to be considered large and viable on a long-term basis, Ne larger than 100 is often considered sufficient. In this instance, considering the estimated effective population, over 1000 reproductive plants are needed.

The limitation to the Ne estimates have to be recognized, the formula used to calculate the effective population size in *Sarcochilus australis* is most appropriate for annual plants. Because *Sarcochilus* is a perennial and the estimate is likely a higher bound for Ne, as the estimated variance in reproductive success among individuals will likely increase among years resulting in smaller Ne. A larger Ne would be possible if and only if individuals that reproduced reduced their reproductive success in future time periods, and those that were non-reproductive become reproductive in following reproductive episodes, thus reducing the variance in reproductive potential among individuals (flower production). Note that the larger the variance among individuals in reproductive success, the smaller the effective population size. Moreover, if a more appropriate estimate of Ne, such as the lifetime reproductive success (Barrowclough & Rockwell, 1993), which considers individual survivorship, long-term reproductive success (multi-year survey) and variation in survivorship, had been included for this long-lived species, the estimate of effective population size would likely be even lower (Tremblay & Ackerman 2001).

Estimates of effective population size including variance in lifetime reproductive success in orchids have rarely been calculated (Tremblay & Ackerman 2001, Chung, et al., 2004). Tremblay & Ackerman (2001) found that using the same formula here for total reproductive potential (pollinaria removal and fruit set) that Ne in three epiphytic orchids of the Caribbean were variable among species (*Lepanthes rupestris*, $F_{is} = 0$, Ne = 0.25, $F_{is} = 1$, Ne = 0.39; *Lepanthes rubripetala*, $F_{is} = 0$, Ne = 0.15, $F_{is} = 1$, Ne = 0.25; *Lepanthes eltoroensis* $F_{is} = 0$, Ne = 0.10, $F_{is} = 1$, Ne = 0.18) and that variance in survivorship and reproductive success (fruit set) was high, suggesting that genetic drift is highly likely in isolated populations (Tremblay & Ackerman, 2003, Tremblay et al, 2005). When they applied a more complex estimation of Ne, using lifetime reproductive success (Barrowclough & Rockwell 1993), the estimates of Ne were frequently smaller, in the range of 5% to 20% of the standing population. The only other survey of Ne in orchids is in the terrestrial *Cremastra appendiculata* in Korea (Chung et al., 2004) where, based on the variance in clone size, Ne as a proportion of standing individuals was estimated as 64% (mean, with a range of 0.64–0.97 in six populations). Chung et al. used a different formula to estimate Ne, but the results are equivalent to the formula used here. Their estimate of variation is a single time period and does not evaluate variance in lifetime reproductive success. Because they chose a character with very small variance (clone size, range 1–12 ramets per genet, with a skewed distribution to one) which may not represent the size of the variance in reproductive success from which to measure Ne, their estimate of Ne is much larger than *Sarcochilus australis* or the *Lepanthes* species; however if they had chosen inflorescence size (which varies from 20–50) they may have found a different result as it is likely that the variation in reproductive potential would be larger, resulting in smaller Ne.

This preliminary survey of *Sarcochilus australis* population structure suggests that a minimum size must be attained for flowering, and that only very large individuals have the possibility of having multiple inflorescences. The variation in floral display in orchids is likely to be a consequence of age, genetics and phenotypic plasticity (Lacey 1986). Effective population size estimates are low and suggest that genetic drift could be occurring at the Kinglake site if *Sarcochilus* population sizes are not more than of 500 reproductive individuals (for an Ne of 50 individuals, approximately 10% of the standing population). Consequently it is likely that high inbreeding coefficients (Fis) would be found if genetic variation were surveyed, unless gene flow among populations of *Sarcochilus australis* is high. This is unlikely to be the case as estimates of gene flow in orchids are commonly low (Tremblay & Ackerman 2003, Tremblay et al., 2005). Moreover, the closest extant populations of *Sarcochilus australis* are in Bunyip State Park c. 60 km away. It is possible that in the past there were other closer populations, and that gene flow among local populations occurred, but, as a result of forest clearing and drying of the gullies, no other surviving populations at Kinglake are known.

Acknowledgements

I thank John Evans for showing me the site and a great day in the field. Appreciation goes to Jeff Jeanes for comments and discussion on the orchids of Victoria.

References

Ackerman, J.D., Sabat, A. & Zimmerman, J.K. (1996) Seedling establishment in an epiphytic orchid: an experimental study of seed limitation. *Oecologia* 106: 192–198.

Backhouse, G. & Jeanes, J. (1995) *The orchids of Victoria.* (Melbourne University Press: Carlton, Australia).

Barrowclough, G.F. & Rockwell, R.F. (1993) Variance in Lifetime reproductive success: estimation based on demographic data. *American Naturalist* 141: 281–295.

Bayman, P., Gonzalez, E.J., Fumero, J.J. & Tremblay, R.L. (2002) Are fungi necessary? How fungicides affect growth and survival of the orchid *Lepanthes rupestris* in the field. *Journal of Ecology* 90: 1002–1008.

Bishop, T. (1996) *Field guide to the orchids of New South Wales and Victoria.* (University of New South Wales Press, Sydney).

Calvo, R.N. & Horvitz, C.C. (1990) Pollinator limitation, cost of reproduction, and fitness in plants: a transition matrix demographic approach. *American Naturalist* 136: 499–516.

Chung, M.Y., Nason, J.D. & Chung, M.G. (2004) Implications of clonal structure for effective population size and genetic drift in a rare terrestrial orchid, *Cremastra appendiculata. Conservation Biology* 18: 1515–1524.

Coates, F., Lunt, I. & Tremblay, R.L. (2006) The effect of fire, rainfall, herbivory on population dynamics of a threatened terrestrial orchid from south-eastern Australia, *Prasophyllum correctum* D.L. and consequences for management. *Biological Conservation* 129: 59–69.

Coxson D.S., McIntyre D.D. & Vogel V.J. (1992) Pulse release of sugars and polols from canopy bryophytes in tropical montane rain forest (Guadaloupe, French West Indies). *Biotropica* 24: 121–133.

Enright, N. & Ogden, J. (1979) Applications of transition matrix models in forest dynamics: *Araucaria* in Papua New Guinea and *Nothofagus* in new Zealand. *Australian Journal of Ecology* 4: 3–23.

Fernández, D.S., Tremblay, R.L., Ackerman, J.D., Rodríguez, E. & López, L.N. (2003) Reproductive potential, growth rate and light environment in *Lepanthes rupestris* Stimson. *Lankersteriana* 7: 73–76.

Franklin I.R. 1980. Evolutionary change in small populations. In: Soulé M, Wilcox BA, eds. *Conservation biology: evolutionary-ecological perspective* MA: Sinauer, Sunderland. pp. 135–150.

Harper, J.L. (1977) *Population biology of plants* (Academic Press: London).

Herrera, C.M. (1991) Dissecting factors responsible for individual variation in plant fecundity. *Ecology* 72: 1436–1448.

Herrera, J. (2004) Lifetime fecundity and floral variation in *Tuberaria guttata* (Cistaceae), Mediterranean annual. *Plant Ecology* 172: 219–225.

Heywood, J.S. (1986) The effect of plant size variation on genetic drift in populations of annuals. *American Naturalist* 127:851–861.

Hirayama, D., Itoh, A & Yamakura, T. (2004) Implications from seeds traps for reproductive success, allocation and cost in a tall tree species *Lindera erythrocarpa. Plant Species Biology* 19: 185–196.

Husband, B.C. & Barrett, S.C.H. (1992) Effective population size and genetic drift in tristylous *Eichhornia paniculata* (Pontederiaceae). *Evolution* 46:1875–1890.

Jack, K.W. (1971) The influence of tree spacing on Sitka spruce growth. *Irish Forestry* 28: 13–33.

Kery, M., Matthies, D. & Spillman H.H. (2000) Reduced fecundities and offspring performance in small populations of the declining grassland plants *Primula veris* and *Gentiana lutea. Journal of Ecology* 88:17–30.

Kimura, M. & Crow, J.F. (1963) The measurement of effective population number. *Evolution* 46: 17:279–288.

Kull, T. (2002) Ecology: Population dynamics of north temperate orchids. Pp. 139–165. in: T. Kull & J. Arditti (Eds.) *Orchid Biology: Reviews and Perspectives VIII* (Kluwer Academic Publishers).

Lacey, E.P. (1986) The genetic and environmental-control of reproductive timing in a short-lived monocarpic species *Daucus carota* (Umbelliferae). *Journal of Ecology*. 74: 73–86.

Metcalf, J.C., Rose, K.E. & Rees, M. (2003) Evolutionary demography of monocarpic perennials. *Trends in Ecology and Evolution*. 18: 471–480.

Øien, D.I. & Moen, A. (2002). Flowering and survival of *Dactylorhiza lapponica* and *Gymnadenia conopsea* in the Sølendet Reserve, Central Norway. Pp. 3–22. in: P. Kindlmann, J.H. Willems & D.F. Whigham (Eds.). *Trends and fluctuations and underlying mechanisms in terrestrial orchid populations* (Backhuys: Leiden).

Otero, J.T., Ackerman J. D. & Bayman P. (2002) Diversity and host specificity of endophytic *Rhizoctonia*-like fungi from tropical orchids. *American Journal of Botany* 89: 1852–1858.

Pino, J., Sans, X.F. & Masalles, R.M. (2002) Size-dependent reproductive pattern and short-term reproductive cost in *Rumex obtusifolius* L. *Acta Oecologica* 23: 321–328.

Pócs, T. (1980) The epiphytic biomass and its effect on water balance of two rain forest types in the Uluguru Mountains (Tanzania, East Africa). *Acta Botanica Hungarica* 26: 143–167.

Primack R.B. & Hall, P. (1990) Cost of reproduction in the pink lady's slipper orchid: a four year experimental study. *American Naturalist* 136: 638–656.

Proctor, M.C.F. (1982) Physiological ecology, water relations, light and temperature response and carbon balance. Pp. 333–381. In A.J.E. Smith (Ed.) *Bryophyte ecology* (Chapman & Hall: Cander).

Rivera Gómez, N., Tremblay, R.L. & Meléndez-Ackerman, E. (2006) Density Dependent Effects in a Lithophytic and Epiphytic Orchid. *Folia Geobotanica* 41: 107–120.

Shapiro, S.S. & Wilk, M.B. (1965) An analysis of variance test for normality (complete samples). *Biometrika* 52: 591–611.

Tremblay, R.L. & Ackerman J. D. (2003) The genetic structure or orchid populations and its evolutionary importance. *Lankersteriana* 7: 87–92.

Tremblay, R.L. & Ackerman, J.D. (2001) Gene flow and effective population size in *Lepanthes* (Orchidaceae): a case for genetic drift. *Biological Journal of the Linnean Society* 72: 47–62.

Tremblay, R.L., Ackerman, J.D., Zimmerman, J. K. & Calvo, R. (2005) Variation in Sexual Reproduction in Orchids and its evolutionary Consequences: A Spasmodic Journey to Diversification. *Biological Journal of the Linnean Society*, 84: 1–54.

Tremblay, R.L, Zimmerman, J., Lebrón, L., Bayman, P., Sastre, I., Axelrod, F. & Alers-Garcia. J. (1998) Ecological correlates of rarity in the epiphytic orchid *Lepanthes caritensis* (Orchidaceae). *Biological Conservation* 85: 297–304.

Wesselingh, R.A., Klinkhamer, P.G.L., de Jong, T.J. & Boorman, L. (1997) Threshold size for flowering in different habitats: effects of size-dependent growth and survival. *Ecology* 78: 2118–2132.

Whigham, D.F. & O'Neill, J. (1988) The importance of predation and small scale disturbance to two woodland herb species. Pp. 243–252 in: M.J.A. Werger, P.J.M. van der Aart, H.J. During & J.T.A. Verhoerven (Eds.) *Plant form and vegetation structure* (SPB Academic Press: The Hague, The Netherlands).

Willems, J.H., Balounová, Z. & Kindlmann, P. (2001) The effect of experimental shading on seed production and plant survival of *Spiranthes spiralis* (Orchidaceae). *Lindleyana* 16, 31–37.

Wright S. (1931) Evolution in Mendelian population. *Genetics* 16: 97–159.

Wright S. (1939) Statistical genetics in relation to evolution: actualités scientifiques et industrielles. 802. *Exposés de biometrie et de la statistique biologiques, XIII* (Paris: Hermann & Cie).

Wright S. (1968) *Evolution and the genetics of populations, Vol. 1. Genetics and biometric foundations.* (University of Chicago Press: Chicago).

Wright, S. (1977) *Evolution and genetics of populations Experimental results and evolutionary deductions.* (University of Chicago Press: Chicago).

Manuscript accepted 9 August 2006

The natural distribution and ecology of *Blandfordia cunninghamii* (Blandfordiaceae)

David Coleby

Convener, Sublime Point Bushcare Group, 11 Willoughby Road Leura NSW 2780, AUSTRALIA.

Abstract: A survey covering almost all known sites and most areas of potential habitat of the rare plant *Blandfordia cunninghamii* (family Blandfordiaceae) in 2004 recorded over 4000 plants from 27 locations, with 80% of the plants in the upper Blue Mountains west of Sydney (lat 33° 40' S, long 150° 20' E), and the remainder as a disjunct occurrence on Mount Kembla in the Illawarra. Habitat requirements of *Blandfordia cunninghamii* were found to be southern aspect (SE to SW), a slope of > 30°, high rainfall (>1200 mm a year), good drainage, partial canopy cover (30-50%), and acid clayey sands with a pH of 4.5-5, at an altitude between 500 and 950 m.

Using International Union for Conservation of Nature (IUCN) parameters, we consider that the number of plants (less than 10 000), their Extent of Occurrence (940 square km), Area of Occupancy (80 km^2) are below the threshold for Vulnerable. There is observed decline in habitat and numbers and we conclude that there may be less than 10 locations (under IUCN definitions). This would mean that the species could be considered Vulnerable under IUCN Criteria.

***Cunninghamia* (2006) 9(4): 537-544**

Introduction

Blandfordia cunninghamii is one of four species of *Blandfordia* in Australia, all confined to the eastern states, three on the mainland, and one, *Blandfordia punicea* (Labill) Sweet, in Tasmania. All are known colloquially as Christmas Bells. All three mainland species occur in New South Wales. *Blandfordia nobilis* Sm is endemic in coastal regions south of Sydney (34° S) to about Bega (36° S). *Blandfordia grandiflora* R.Br ranges from Sydney to Fraser Island in Queensland (24° S), including occurrences in the lower and middle Blue Mountains (Porter et al 1992; Johnson 1998). *Blandfordia cunninghamii* (Lindl) is a tufted perennial herb with leaves up to 1 m long. It is a rare species (Briggs & Leigh 1995), and is restricted to a narrow range of habitats in the Blue Mountains (lat 33° 40' S, long 150° 20' E) and the Illawarra areas of eastern New South Wales (Porter 1992). The objectives of the Sublime Point Bushcare Group (SPBG) survey were to provide baseline data on the current extent and abundance of *Blandfordia cunninghamii*, and to determine its conservation status and preferred habitat.

Methods

We (the SPBG) began the survey of *Blandfordia cunninghamii* in 2004 by visiting the twelve sites surveyed by Porter (1992), and two other sites identified by Porter (pers. comm.) (at the Golden Stairs, Narrow Neek and at the head of Roberts Pass, south Leura). We then extended the survey to cover as many other known occurrences and likely habitat of the species as we could.

Published accounts of the habitat of *Blandfordia cunninghamii* describe it as similar to that of other *Blandfordia* species; that *Blandfordia cunninghamii* grows in wet places, even hanging swamps - “hanging swamps” (Johnson 1996), “damp, somewhat peaty places” (Baker et al 1984), “damp places in the Blue Mountains” (Carolin & Tindale 1994; Greig 1999), “damp shallow sandy and peaty soils, often on sandstone cliff edges” (Quirico 1993), “shrub swamps and sedge swamps, seepage lines and soaks” (Benson et al 1996), “Blue Mountains sedge swamps” (Smith & Smith 1995a, 1995b), “dense swamp vegetation and wet areas in other sites” (Smith & Smith 1999).

Development of a predictive model spared us unnecessary time and effort. Initially we searched potential habitat based on published information, ie a wet area, such as a hanging swamp. We examined three steep hanging swamps, each greater than a hectare, with southerly, easterly, and westerly aspects respectively. We also examined two large sedgeswamps each with a slope of less than 1:100. In all cases the main vegetation was either Button Grass, *Gymnoschoenus sphaerocephalus* or Pouched Coral-fern, *Gleichenia dicarpa*, or both, but no *Blandfordia cunninghamii* was found.

We modified the model to include habitat outside hanging swamps, and eventually completely rejected hanging swamps and other wet places as suitable habitat. Distribution patterns appeared related to steep southern slopes. The GDA/MGA 1:25 000 Topographic Maps (Central Mapping Authority of New South Wales) enabled us to identify and examine many steep slopes with southern aspects.

Because *Blandfordia cunninghamii* occurs in high rainfall areas, the number of potential habitat sites was also reduced by only including areas with a rainfall of at least 1200 mm a year (data from the Australian Bureau of Meteorology 1991).

At each site we searched to establish the boundary of the occurrence of *Blandfordia cunninghamii*. We then covered the whole area of the occurrence with 10 x 10 m contiguous quadrats. This allowed us to count every plant. 10 x 10 m quadrats were a practical consideration because the terrain was always steep: often it was on cliff faces, though because of this the actual quadrat area (100 m^2) on the slope was recorded, not its projected horizontal area. In each quadrat we recorded the number of plants, the number in flower, the number of juveniles, and habitat parameters.

We measured slope with a clinometer (accurate to ±1°), aspect with a compass, and estimated canopy coverage according to Specht (1974). We recorded altitude, landform type, and vegetation community type. We also recorded non-habitat parameters such as the Map Grid of Australia (MGA) map references, the ownership status of the land, and time and date of survey. Details from the survey have been lodged with the library of the National Herbarium of NSW in the Royal Botanic Gardens, Sydney.

We took care to distinguish between *Blandfordia cunninghamii* and similar species with long leaves about 10 mm wide, such as *Lomandra longifolia* and *Gahnia sieberiana*. Unless new and short, leaves of *Blandfordia cunninghamii* are seldom erect: they lie flat on the sloping surface of their habitat which, being a steep slope, is always downhill. This feature is most noticeable in summer or in drought. Well-established plants may be decades old, and new leaves lie on top of a pile of still-attached dead leaves. Such piles can be 200 mm high.

Results and discussion

Natural distribution of Blandfordia cunninghamii

The main distribution of *Blandfordia cunninghamii* is in the upper Blue Mountains, along the southern cliff-top slopes between Katoomba–Leura–Wentworth Falls, a distance of about 6 km (Fig. 1). Within this relatively small area we found plants at 18 locations many of which had not been previously recorded. These new sites were found by applying our predictive model.

There are seven other Blue Mountains occurrences, isolated from the main Katoomba–Leura–Wentworth Falls concentration, and from each other, by distances greater than 2 km (Fig. 2); at Mt Tomah; Mt Wilson; Blackheath; Mt Flat Top, off the Mt Hay Road; and south of Wentworth Falls, on the Kings Tableland in a cave west of the Queen Victoria Hospital; on the southern flank of Harris Hill; and south of McMahons Point on a clifftop overlooking Lake Burragorang.

About 80 km south-east of the upper Blue Mountains, there is a major outlying population at Mount Kembla near Wollongong. There are records for two intermediate occurrences; one at Bargo River near Yerrinbool, where a specimen had been collected in January 1932, but only came to our attention in 2005 (D. Benson pers. comm.) after our survey was completed. At the other, near the Georges River in Wedderburn (reported sighting by Payne (1989), but not confirmed with a specimen,), we were unable to find any *Blandfordia cunninghamii* plants despite careful searching.

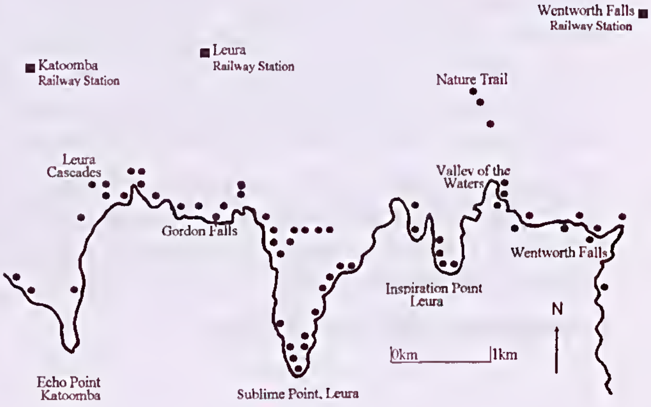


Fig. 1. The main upper Blue Mountains distribution of *Blandfordia cunninghamii* is along the southern cliff-top slopes from Katoomba–Leura–Wentworth Falls.

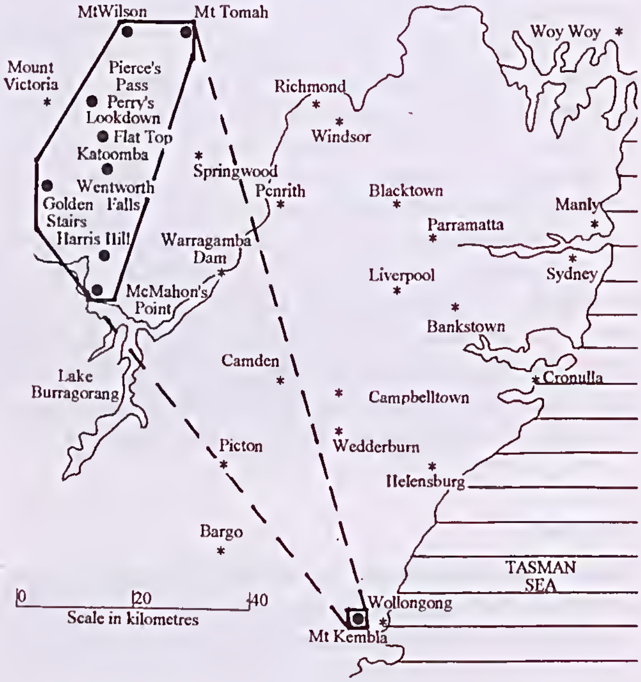


Fig. 2. Extent of natural occurrence of *Blandfordia cunninghamii* in New South Wales.

Our survey recorded over 4000 *Blandfordia cunninghamii* plants from 27 locations (Table 1). Mean population size for the 27 locations was 159 (±se=44.6) ranging from 3 plants at Popes Glen, Blackheath to 900 at Mt Kembla. Plant numbers in individual 100 m^2 quadrats ranged from 1 and 62. Mean plant densities at locations ranged from 150/ha (i.e. 1.5 per 100 m^2) at Blackheath to 2900/ha at both Mt Kembla and Harris Hill and there appeared to be a trend for greater densities in larger populations. Site areas ranged from 100 m^2 near Little Switzerland Rd and Queen Victoria Hospital at Wentworth Falls, to 3100 m^2 at Mt Kembla. The total area for the 27 sites was only 3.4 ha.

The predictive model was not always successful. We failed to find any *Blandfordia cunninghamii* on the steep slopes of the Erskine Range, or Round Hill, or Double Hill, all on Kings Tableland at Wentworth Falls. Nor did we find any on the steep slopes of Fortress Ridge, The Pinnacles, Lockley Pylon and Mt Hay, north of Leura. There were many other failures in other areas of apparently suitable habitat.

Our survey was not completely exhaustive, merely exhausting. There may well be other *Blandfordia cunninghamii* sites, especially in the Blue Mountains. Potential sites are the southern slopes above cliffs along the Kings Tableland in Wentworth Falls, on the southern flank of Mount Solitary, along the length of Narrow Neck in Katoomba, and bordering the Grose Valley from Bell to Linden. There may also be other occurrences in the Illawarra. Occurrences in any of these locations would make little difference to our measured EOO. The record for Bargo River suggests that despite the low rainfall and low altitude there may be other, probably riparian, occurrences in the middle of the long triangular EOO area (Fig. 2), and it is possible that some such sites might have been in the valleys of the Nepean and Avon Rivers immediately to the east, and now flooded by the Metropolitan Water Catchment dams (D. Benson pers. comm.)

Table 1: *Blandfordia cunninghamii* locations (IUCN locations 1-9 and subpopulations a-r), site areas, local population sizes and plant densities for 10 x10m quadrats sites recorded by SPBG in 2004.

Location (# denotes Porter site)		Site area (m^2)	No. of plants	Plant density per 100 m^2
1	Skyline Road, Mt Tomah #	300	20	6.6
2a	Pierces Pass, Mt Wilson #	800	49	6.1
2b	Perrys Lookdown, Blackheath #	400	25	6.3
3	Eastern end of Popes Glen, Blackheath #	200	3	1.5
4	Southern flank of Flat Top, Mt Hay Road, Leura	400	21	5.3
5a	Golden Stairs, Narrow Neck, Katoomba	1200	109	9.1
5b	Bonnie Doon, below old brickworks, Katoomba	400	22	5.5
5c	Prince Henry Cliff Walk, Katoomba #	1600	92	5.8
5d	Fern Bower, below Prince Henry Cliff Walk, Leura	200	6	3.0
5e	Leura Cascades #	500	33	6.6
5f	Prince Henry Cliff Walk, Gordon Falls to The Rock	1600	202	12.6
5g	Gordon Falls, Pool of Siloam, Lyre Bird Dell, Leura #	800	77	9.6
5h	Golf Links Lookout to Sublime Point, Leura #	1700	202	11.9
5i	South of Cliff View Drive, Sublime Point, Leura	6000	662	11.0
5j	Southwest side of Sublime Point, Leura	2700	436	16.1
5k	Southeast side of Sublime Point, Leura	4500	540	12.0
5l	Isobel Bowden Ridge, Leura	200	7	3.5
5m	Inspiration Point and Roberts Pass, Leura	800	78	9.8
5n	Nature Trail, Leura	900	72	8.0
5o	National Pass, Wentworth Falls #	1000	50	5.0
5p	Overcliff-Undercliff walks, Wentworth Falls #	2200	169	7.7
5q	Western side of Weeping Rock, Wentworth Falls #	300	11	3.7
5r	West of Little Switzerland Road, Wentworth Falls	100	8	8
6	West of Queen Victoria Hospital, Kings Tableland	100	15	15
7	South of Harris Hill, Kings Tableland	1500	434	28.9
8	McMahons Point, Kings Tableland	500	50	10
9	Southern flank of Mt Kembla, Illawarra #	3100	900	29.0
Totals		**34000**	**4293**	**12.6**

Comparison with Porter's 1990 survey

We were able to relocate most of Porter's (1992) 12 occurrences recorded in 1990, except for her single plant at Katoomba Falls, and her colony on Castle Head (Narrow Neck) (Table 2). At the Golden Stairs (Narrow Neck) we recorded 107 plants above and below Bottings Lookout. At the head of Roberts Pass, near Inspiration Point in south Leura, a landslide in the late 1990s wiped out most of the *Blandfordia cunninghamii* in that area; our survey recorded only 4 remaining plants of the 25 seen in 1993.

We found some large differences between Porter's figures and ours (Table 2). At Katoomba Falls, Castle Head (Narrow Neck) and Leura Cascades it is possible that heavy foot traffic from increasing tourism might have caused the reductions in numbers. The marked reductions at Perrys Lookdown and at Govetts Leap (both in Blackheath) we also consider to be real decreases. In the area between Wentworth Falls and Valley of the Waters where we found 230 plants, considerably fewer than Porter's 325, but we have no evidence to suggest why this reduction has taken place. However the increases recorded at Katoomba (Prince Henry Cliff Walk), at Leura (Pool of Siloam to Gordon Falls) and Leura (below Golf Links Lookout) are unlikely to be an actual increases since 1990; it is more likely that our survey identified occurrences missed by Porter. Overall, excluding the Illawarra population, there was no significant difference between Porter's mean number of plants/site (mean =55 ± se 27) and our figure (mean = 48 ± se 20).

The large increase in recorded numbers for the southern flank of Mount Kembla in the Illawarra represents a major increase in the area of habitat previously reported, rather than an increase in the local population since 1990. Our predictive modelling enabled identification of a long cliff line on the southern flank of Mount Kembla, (a cliff not marked on the Wollongong 1:25 000 topographic map),and found to be habitat for 900 plants. These plants grow in about a dozen parallel and vertical fissures, 5-20m high. These fissures are crowded with plants, but 90% are *Blandfordia cunninghamii* plants.

Ecological attributes

Altitude: Occurrences of *Blandfordia cunninghamii* ranged from 950 m (at Narrow Neck, Katoomba) down to 400 m elevation (at Yerrinbool). The possible site at Wedderburn (not confirmed by us), is at 100-200 m elevation.

Rainfall: High rainfall is a crucial factor. Occurrences of *Blandfordia cunninghamii* correlate strongly with records of annual rainfall of over 1200 mm, though not all high rainfall areas support *Blandfordia cunninghamii*. Pymble, a northern coastal suburb of Sydney, and Dharug National Park, west of Gosford, also experience high average annual rainfall (over 1200 mm), but there are no records of *Blandfordia cunninghamii* from these low-altitude locations. Nor was any *Blandfordia cunninghamii* found in low rainfall areas (<1100 mm per year) in our survey, despite having steep southern slopes; eg Hassans Walls near Lithgow. Wedderburn has an annual rainfall of 850 mm.

Drainage: *Blandfordia cunninghamii* does not grow in well-delineated drainage lines which may scour, but rather prefers either (a) drainage slopes which assure broad distribution of rainwater, or (b) crevices and fissures in cliffs. Leaf litter promotes slightly damp, but not wet, soils. Wet soils were encountered only immediately after heavy rain: even then they were ephemeral. Plants were not found in a Blue Mountains hanging swamp, in a sedge swamp, in a clifftop swamp, in a valley swamp or in any other variety or grading of wet places.

Table 2: Comparison of number of plants of *Blandfordia cunninghamii* reported from Porter's locations (1-12) in 1990 and revisited by SPBG in 2004.

Porter sites	Location	No of plants 1990	No of plants 2004
1	Mt Tomah (private property)	20	20
2	Pierces Pass, Mt Wilson	45	49
3	Blackheath (Perrys Lookdown)	40	25
4	Blackheath (Govetts Leap)	~30	3
5	Katoomba, Prince Henry Cliff Walk	25	39
6	Katoomba Falls	1	0
7	Narrow Neck (Castle Head)	3	0
8	Leura Cascades	13	7
7	Leura, Pool of Siloam to Gordon Falls	42	69
10	Leura, below Golf Links Lookout	60	87
11	Wentworth Falls to Valley of the Waters	325	230
12	Mt Kembla	100	900

Aspect: Our survey confirms the southerly aspect for *Blandfordia cunninghamii* previously identified (Porter 1992, Porter et al. 1992). Most plants were found in the sector 160-190° and no plants were found with an aspect further east than 135° (southeast), or with an aspect further west than 225° (southwest) (Fig. 3). None was found in the major sector of 270° from southeast, through north, to southwest.

Topography: Natural occurrences of *Blandfordia cunninghamii* occur in two broad types: either a monotonic slope of 30° or more (Fig. 4a), or a cliff-line L-step (Fig. 4b), usually at an outbreak of a claystone layer in Narrabeen Sandstone, such as the Wentworth Falls claystone. In the cliff-line L-step habitat we found *Blandfordia* plants in three topographical subtypes:

1) at the base of a cliff, in the drip zone, or in small caves behind the drip zone,

2) from the cliff base outwards and down the talus for a short distance, and

3) on vertical cliff faces and on cliff edges, in habitats where moisture is regularly available.

Slope: *Blandfordia cunninghamii* occurs on steep slopes (Porter 1992, Porter et al. 1992). A slope of at least 30° slope is an important factor in determining habitat and except for a few occurrences in small caves, no slope was less than 30°. Most slopes fell between 30-50°, but some were vertical. Although slope confers good drainage, it does not necessarily imply lack of water.

Light regimes: low levels of light appear to be an important habitat factor for growth: in sites on southern slopes and south-facing cliffs, direct sunlight hours are reduced by 50% or more in summer, and by up to 100% in winter. In

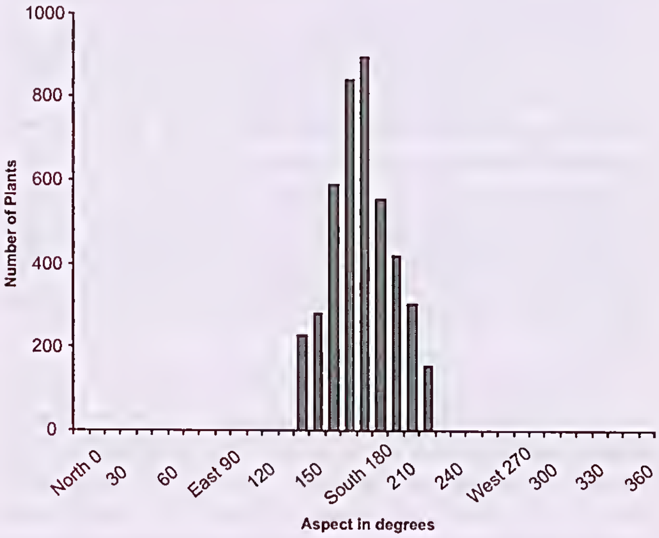


Fig. 3. Number of plants of *Blandfordia cunninghamii* recorded from 10 degree aspect sectors showing concentration on southeast to southwest sites.

Figure 4a: Monotonic slope
Blandfordia cunninghamii

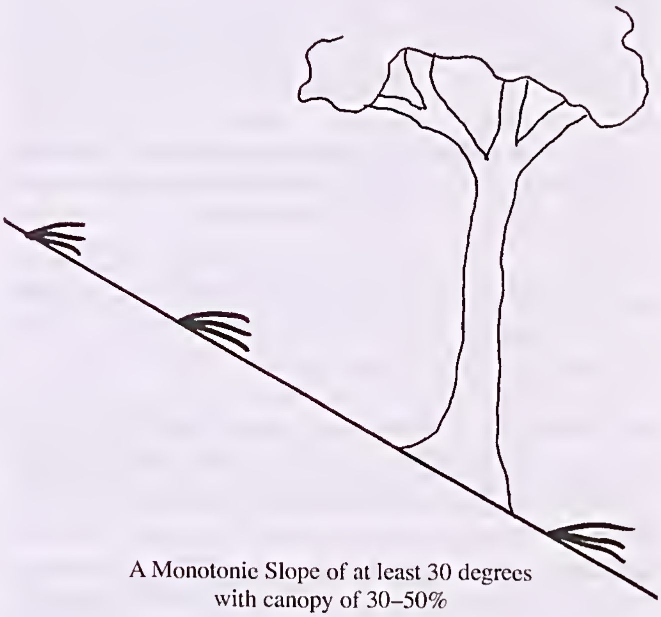


Figure 4b: L-step cliff
Blandfordia cunninghamii

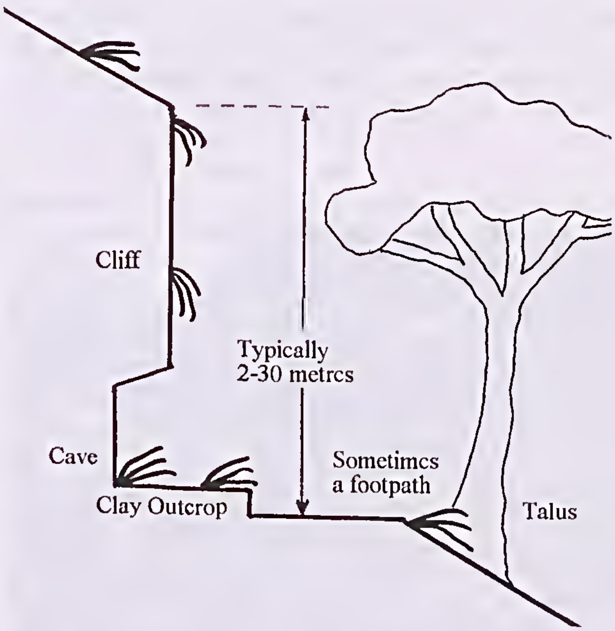


Fig. 4. Natural occurrences of *Blandfordia cunninghamii* occur in two broad landform types: either a monotonic slope of 30° or more (Fig. 4a), or a cliff-line L-step (Fig. 4b), usually at an outbreak of a claystone layer in Narrabeen Sandstone.

winter sites on a southern slope of 33.5° or more receive no direct sunlight all day (the maximum altitude of the midday sun at latitude 33.5° south is 33°). The canopy of trees and shrubs will further reduce indirect or refracted sunlight. This apparent preference for low light regimes may extend to a requirement for a cool root run, but *Blandfordia* plants were never found in the relative dark of rainforest. Where *Blandfordia* plants grow in the southern lee of a cliff or in a cave with a southerly aspect they often receive no direct sunlight all year. Yet the plants flourish, compete favourably with other species, and flower occasionally.

Canopy: In all natural occurrences of *Blandfordia cunninghamii* canopy is variable, but in the range 30-50% usually designated open-forest (Specht 1974). Even on cliffs otherwise devoid of vegetation the cliff itself presents a "canopy" of 50%. Caves also represent a canopy of about 50%. *Blandfordia cunninghamii* were not found in the canopy range up to 25% (such as woodland or open woodland), nor in the canopy range beyond 50% (such as forest or closed-forest).

Soils: *Blandfordia cunninghamii* generally grow in clayey sands of moderate acidity, with a pH of 4.5-5. Spot checks of pH were made during our survey. Many steep southern slopes were unsuitable habitat because the soils were not clayey sands: they were often sandy grits with small stones and rocks. These soils supported *Eucalyptus* woodland and open-forest with a shrub storey of *Acacia*, Epacridaceae, Myrtaceae and Proteaceae, eg the steep southern slope at the junction of the walking tracks to Valhalla and to Asgard Swamp with the Victoria Falls Road (between Bell and Mount Victoria).

Flowers: *Blandfordia cunninghamii* flower rarely except after fire. It would be unusual, in the absence of fire, for more than two per cent to flower in any one year, and often the flowering rate is lower than two per cent. At Mount Kembla, in a total of 900 mature *Blandfordia* plants, only two flowered in 2004. Of the 662 mature plants south of Cliff Drive in Leura, seven flowered in 2004. Flower stems are stout and often up to a metre high, although on exposed cliffs (as at Mount Kembla) they may be only 200 mm high. Occasionally plants have two or more stems. However, it may be that such multiple stems arise from more than one plant; their physical proximity precludes separate identification. Our observations are that the number of flowers per stem can be in the range 12-32. They hang in a dramatic and graceful cluster.

Fire: The importance of fire in the stimulation of flowering and seed set of *Blandfordia cunninghamii* is not clear. However, we note that in one occurrence of 50 plants, south of McMahons Point, burnt in early 2002 in a moderate burn, 15 plants flowered within a year. None has flowered since (2005).

Seeds: A typical seed head may have up to 32 capsules, which, unlike the flower bells, are held vertically upwards. Each capsule has three loculi which dehisce septicidally. Each loculus contains numerous, typically 10-15, hairy brown seeds. A seed head may contain several hundred seeds. Seed set appears to be consistently good, although pollination vectors are not known.

Germination and propagation: Fresh seeds germinate easily, and may be reared by conventional nursery practices, but plants are difficult to bring to flowering maturity. The SPBG propagated some *Blandfordia cunninghamii* seeds and introduced the seedlings into suitable habitat, but none reached maturity. The fate of seeds in natural circumstances is not known, but paucity of juvenile plants in the environment suggests, among other factors, high seed predation.

Generation length: *Blandfordia cunninghamii* generation length is not known, but the low rate of recruitment of adult plants suggests that generation length of *Blandfordia cunninghamii* is not years, but decades. A feature of our survey was the paucity of juvenile plants. Our criterion for a juvenile plant was one which had five leaves or less: differences in leaf length and leaf width were ascribed to slight differences in habitat. The proportion of juveniles in a given population was always less than one percent, and often zero, suggesting a long generation length.

Conservation assessment

International Union for Conservation of Nature (IUCN) rules for assessment of the conservation status of threatened species involve several parameters (IUCN 2001, 2004). For the geographic distribution criterion, estimates are required of Extent of Occurrence and Area of Occupancy. Extent of Occurrence (EOO) is the area of a minimum convex polygon encompassing all known, inferred or projected sites of present occurrence. The EOO for *Blandfordia cunninghamii* is a roughly triangular area of 2300 km^2 from the Blue Mountains in the northwest to the Illawarra in the southeast (Fig. 2). The occurrence of *Blandfordia cunninghamii* on Mount Kembla at Wollongong is separated by about 80 km from the Blue Mountains. Including the Wedderburn and Bargo River occurrences would increase it to about 3000 km^2.

Treating the upper Blue Mountains and Mt Kembla occurrences separately gives an EOO for the Blue Mountains (as shown by the heavy line around that area) of 936 km^2, and an EOO at Mount Kembla of 4 km^2, i.e. a total EOO of 940 km^2.

The IUCN Area of Occupancy (AOO) is the smallest area occupied within the EOO that is essential to the survival of existing populations of the species. Since our sampling plots covered every plant we could locate, our estimate of the AOO is a minimum of 3.4 ha. Additional sites likely to be found in the future would increase our measured AOO, but it is unlikely to increase it beyond 5 ha.

However, there is an IUCN (2001) caveat noting that 'the finer the scale at which the distributions or habitats of taxa are mapped, the smaller the area will be that they are found to occupy, and the less likely it will be that range estimates (at least for AOO) exceed the thresholds specified in the criteria.' We converted our 10 x 10m sampling to the 2 x 2 km scale using IUCN Guidelines (2004), a process that increased the AOO from 3.4 ha to 80 km^2.

With an EOO of 940-2300 km^2 and an AOO of 80 km^2 *Blandfordia cunninghamii* meets the first part of the IUCN Geographic Range Rule B (either for B1or B2) requirement for a Vulnerable taxon. However to comply at least two of subrules a-c must also apply.

Compliance with subrule a requires severe fragmentation or existence at no more than 10 locations. IUCN defines *Locations* as geographically or ecologically distinct areas in which a single threatening event can rapidly affect all individuals of the taxon present. The size of a Location depends on the area covered by the threatening event and may include part of one or many Subpopulations.

We recorded 8 separate geographic locations (Table 1, Fig. 2) and regard the remaining populations in the upper Blue Mountains the Katoomba–Leura–Wentworth Falls occurrences as one location with 18 subpopulations as per IUCN (2001). For example a severe bushfire travelling north and east up the Jamison Valley could constitute a major threatening event, and would encompass several Subpopulations. The close proximity of the subpopulations may also make them vulnerable to disease. The related *Blandfordia punicea* in Tasmania is recognized as a susceptible species to the pathogen *Phytophthora cinnamomi* (Podger et al 1990), and it is likely that *Blandfordia cunninghamii* is similarly susceptible. The pathogen is likely to be spread in soil and water and the given proximity to urban development to most subpopulations along the Katoomba–Leura cliffline and the network of footpaths and roads between sites, the chance of spread is high. *Phytophthora cinnamomi* is listed as a Key Threatening Process under the NSW *Threatened Species Conservation Act*).

Compliance with subrule b requires continuing decline, observed, inferred or projected. Comparing our survey with the limited data from Porter (1992) indicates there is a continuing decline in quality of habitat and in number of mature individuals at some sites particularly in relation to increased track use. Ongoing threats include urban run-off, trampling and climate change. All are insidious, longterm, and difficult to control. Many *Blandfordia* occurrences, especially between Katoomba and Wentworth Falls, are on or near walking tracks, and often just below private property or public areas where pollution is the norm and declines in numbers observed in areas such as Leura Cascades and Katoomba Falls may have been caused by urban run-off and trampling. It seems unlikely however that declines in numbers at Perrys Lookdown, Govetts Leap or Wentworth Falls could be attributed to either trampling or pollution. Rainfall in the Blue Mountains in recent years has been low and climate change poses potential threats. In the five years since 2000, rainfall has been well below average over the geographic range of *Blandfordia cunninghamii.*

Illegal flower and seed collecting are also threatening events, but the hidden nature of many habitats, and their relative inaccessibility suggests that these events may not be crucial, in contrast with the same threats to other *Blandfordia* species.

Subrule c Extreme fluctuations is not met by this species as it appears to be a relatively long-lived plant with low turnover of plants and only intermittent periods of recruitment. No extreme fluctuations were noted.

We therefore consider that *Blandfordia cunninghamii* could meet IUCN requirements as a Vulnerable species.

Acknowledgements

We thank the Blue Mountains City Council for their support, in particular Frank Garofalow (Program Manager, Ecosystems Planning), Matthew Chambers (Environmental Scientist) and Dave Melick (former Environmental Scientist). The National Parks and Wildlife Service in Hurstville (now part of Dept of Environment and Conservation), especially David Keith (Manager, Vegetation Dynamics Unit) provided valuable assistance in relation IUCN requirements. At the NPWS Blue Mountains Regional Office in Katoomba and at the District Office at the Heritage Centre at Blackheath we received ready support from Ian Brown (formerly District Operations Manager), and Greg Wellham (formerly Manager, Blue Mountains Central) who sanctioned the SPBG survey in the National Park. At the National Herbarium of NSW in Sydney, Carolyn L Porter helped us to identify many of the locations in her 1990 survey, and Doug Benson gave encouragement when it was most needed. And finally a heartfelt thank-you to the enthusiastic members of the Sublime Point Bushcare Group: Rae Druitt, Joan Gahl and Imre Gahl.

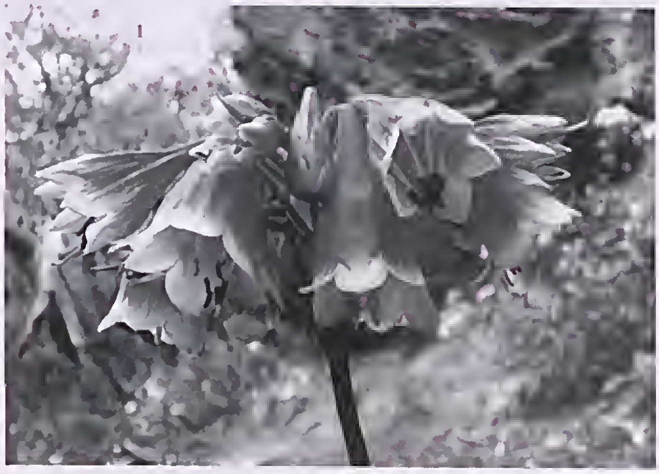


Fig. 5. Distinctive red and yellow flower of *Blandfordia cunninghamii.*

References

Baker, M, Corringham, R, and Dark, J, (1984), *Native plants of the upper Blue Mountains* (Three Sisters Productions: Winmalee).

Benson, D, Howell, J, and McDougall, L, (1996) *Native plant species in the Hawkesbury-Nepean catchment* in *Mountain Devil to mangrove* (Royal Botanic Gardens: Sydney).

Briggs, J D, and Leigh, J H, (1995) *Rare or threatened Australian plants* (ROTAP) 1995, Revised Edition (CSIRO Centre for Plant Biodiversity Research and the Australian Nature Conservation Agency: Canberra).

Bureau of Meteorology (1991) *Sydney climatic survey*.

Carolin, R C, & Tindale, M D, (1994) *Flora of the Sydney region*, Fourth Edition, (Reed, Griffin Press).

Greig, D, (1999) *Field guide to Australian wildflowers* (New Holland).

IUCN (2001) IUCN Red List Categories and Criteria: Version 3.1, (Species Survival Commission of the International Union for Conservation of Nature and Natural Resources, IUCN, Gland, Switzerland, and Cambridge, UK).

IUCN (2004) Guidelines for Using the IUCN Red List Categories and Criteria, (Species Survival Commission of the International Union for Conservation of Nature and Natural Resources, IUCN, Gland, Switzerland, and Cambridge, UK).

Johnson, K, (1996) Chapter 19, Blandfordia, in *Native Australian plants: horticulture and their uses* (K A Johnson & M Burchett eds.) (UNSW Press: Sydney).

Johnson, K, (1998) Blandfordia, pages 487-492 in *The New Rural Industries, a Handbook for Farmers and Investors* (K W Hyde ed) (Rural Industries Research and Development Corporation).

Payne, R, (1989) unpublished report, (copy held at National Herbarium, Royal Botanic Gardens: Sydney).

Podger, F., Palzer, C. & Wardlaw, T. A. (1990) Guide to the Tasmanian distribution of *Phytophthora cinnamomi* and its effects on native vegetation. *Tasforests* 2(1) (Forestry Commission of Tasmania: Hobart).

Porter, C L, (1992) Distribution and abundance of *Blandfordia cunninghamii* Lindley, Blandfordiaceae. *Cunninghamia* 2(4): 523-532.

Porter, C L, Morrison, D A, & Johnson, K A, (1992) Morphological variation within the genus *Blandfordia* (Liliaceae) in relation to its environment. *Australian Systematic Botany* 5: 373-385.

Quirico, A L, (1993) Blandfordiaceae, in *Flora of New South Wales volume 4* (G J Harden ed.) (UNSW Press: Kensington).

Smith, P, & Smith, J, (1995a) Flora and Fauna Study for Blue Mountains Environmental Management Plan: Study Area 2: Katoomba to Wentworth Falls.

Smith, P, & Smith, J, (1995b) Flora and Fauna Study for Blue Mountains Environmental Management Plan: Study Area 3: Bullaburra to Linden.

Smith, P, & Smith, J, (1999) Flora and Fauna of Wentworth Falls Catchment. Report to Blue Mountains City Council, October 1999.

Specht, R L, Roe, E M, & Boughton, V H, (1974) Conservation of major plant communities in Australia and Papua New Guinea. *Australian Journal of Botany Supplementary Series* No 7 (CSIRO).

Manuscript accepted 14 March 2006

African Olive (*Olea europaea* subsp. *cuspidata*) as an environmental weed in eastern Australia: a review

Peter Cuneo[1] *and Michelle R. Leishman*[2]

[1]Botanic Gardens Trust, Sydney, Mount Annan Botanic Garden, Mount Annan NSW 2567, AUSTRALIA.
Email: peter.cuneo@rbgsyd.nsw.gov.au
[2]Department of Biological Sciences, Macquarie University NSW 2109, AUSTRALIA

Abstract: African Olive, *Olea europaea* subsp. *cuspidata* (Wall. ex G.Don) Cif. (family Oleaceae) is a dense-crowned tree introduced into Australia for horticulture in the mid 19th century. In recent decades, African Olive has become an aggressive woody weed, capable of forming a dense and permanent canopy in a wide range of vegetation types in south-west Sydney and beyond. Characteristics of African Olive invasion in south-west Sydney, and its seed dispersal by frugivorous birds are consistent with experience from Norfolk Island and Hawaii. We use records and aerial photographs from Mount Annan Botanic Garden and other bushland areas in south-west Sydney to describe the invasion stages and impacts of African Olive. The capacity for African Olive to establish in both temperate and subtropical zones, underlie the potential for spread well beyond current distribution in New South Wales. Research is now required to further develop control techniques and ecological restoration strategies for areas of heavy African Olive infestation. Mapping of current locations and a coordinated control strategy for African Olive is required to prevent future permanent loss of native plant diversity.

***Cunninghamia* (2006) 9(4): 545–577**

Introduction

European Olive (*Olea europaea* subsp. *europaea*) is well documented as an environmental weed in Australia, particularly in the Adelaide region of South Australia where cultivated trees have been abandoned and their progeny have established in remnant bushland (Spennemann & Allen 2000a, Crossman 2002). African Olive (*Olea europaea* subsp. *cuspidata*) was introduced to Australia in the mid 19th century for horticultural purposes, and is now an aggressive weed in the Camden—Campbelltown and Hunter Valley areas of New South Wales, as well as on Norfolk Island. It is highly invasive in drier woodlands, riverine environments, coastal headlands and dune systems (Muyt 2001). African Olive is a declared noxious weed in NSW and South Australia, and listed nationally as a potential environmental weed (Csurches & Edwards 1998). African Olive outcompetes established native vegetation, casting dense shade which prevents the regeneration of native plants (DEH 2004). Following an extensive vegetation mapping project in western Sydney, Tozer (2003) identified African Olive as a management problem requiring urgent attention to ensure the conservation of biological diversity. In contrast to studies on the invasiveness of the cultivated European Olive, African Olive has received relatively little research attention on its ecology and biology as an environmental weed under Australian conditions.

In this review we describe the taxonomy of African Olive, its history of introduction into Australia and subsequent distribution, and key aspects of its biology that may contribute to its success as an environmental weed. We then describe a model of the stages of African Olive invasion, based on evidence from aerial photographs, observations and archives at Mount Annan Botanic Garden, Sydney and in bushland remnants across western Sydney over a 15-year period. Botanical names used follow those used by the National Herbarium of New South Wales.

African Olive — botanical relationships and biogeography

African Olive is part of the *Olea europaea* complex, which includes the edible European Olive, long-cultivated throughout the Mediterranean region. The *Olea europaea* complex extends from the Canary Islands and Madeira westwards across the Mediterranean, and south-west Asia to the Sino-Himalayan region, and south through eastern Africa to southern Africa (Green & Wickens 1989). African Olive is part of a tropical wild olive group, geographically isolated from their Mediterranean relatives and adapted to totally different climates (Zohary 1995).

The genus *Olea* occurs across a very wide geographic range with 33 species and nine subspecies described (see Green (2002) for a taxonomic account of the genus). In Green's (2002) recent revision of *Olea*, the name *Olea europaea* subsp. *cuspidata* is proposed for the wild olive occurring in South to North-East Africa and southwest Asia, and naturalised in Hawaii, Australia, New Zealand and Norfolk Island. In Australia both the European Olive (*Olea europaea* subsp. *europaea*) and African Olive (*Olea europaea* subsp. *cuspidata*) have naturalised.

In NSW African Olive was previously known as *Olea africana* and more recently *Olea europaea* subsp. *africana*. It is readily distinguished from European Olive by the presence of a hooked leaf apex and a lower leaf surface which is green or yellowish brown (Harden 1992) (see Table 1 for diagnostic characteristics).

Ecology of African Olive in its native range

The major area of natural distribution for African Olive is eastern Africa, where it extends throughout the eastern African states from the southern tip of Africa to the north-east regions. It is commonly recorded for the countries of Tanzania, Kenya, Ethiopia, Mozambique, Sudan, Namibia, Somalia and South Africa. From eastern Africa, the distribution extends into the Middle East region with occurrences in Yemen and Saudi Arabia. A significant Asian centre of African Olive distribution is northern India, Afghanistan, Pakistan and Kashmir. The most easterly natural distribution is China, particularly the drier parts of Yunan and Sichuan (Green 2002).

In its native range African Olive is a small-medium evergreen tree which grows in a wide range of habitats, including open woodlands, rocky mountain slopes and along watercourses (Table 2). African Olive trees have a dense bushy habit and typically grow to 5–10 m in height (Palgrave 1983). When growing under ideal conditions such as stream banks, trees can attain a height of 15–18 m. In dry exposed conditions trees develop a bushy, rounded habit with a dense canopy and gnarled trunk. Grey-brown flaky bark develops on the older branches. Sweetly scented flowers are produced in the summer months (October – December in its native range) and are 6–10 mm, greenish white in colour and held in loose axillary heads. The fleshy ovoid fruits develop from March to July (native range) and are 7–10 mm in size turning dark brown to black on maturity. Fruiting trees in their natural

Table 1: A comparison between the two naturalised Olive species in Australia.

Taxon	Leaf characteristics	Field characteristics/comments
African Olive *Olea europaea* subsp. *cuspidata*	6–10 cm long 10–25 mm wide Undersurface pale green – yellowish brown Leaf tip with hooked apex Mid veins yellowish green.	Fruit – purple black thinly fleshed drupe, round 6–7 mm diameter Dense multi – trunked tree with dark green glossy foliage. Naturalised/weedy in coastal districts
European Olive *Olea europaea* subsp. *europaea*	3–7 cm long 8–10 mm wide Undersurface whitish – silver grey Hooked leaf apex absent Leaf margins slightly recurved	Fruit – purple/black oval drupe 15–25 mm long x 6 mm diameter. Dense multi – trunked tree with dark green/silver underside foliage sheen. Naturalised in inland districts with dry climate

Table 2: Examples of natural habitat types for African Olive – Data obtained from records of the East African Herbarium, Nairobi.

Location	Habitat description
Ketumbane Mtn Tanzania	A much branched evergreen tree up to 16 m tall. Growing in association with *Juniperus procera* on the steep sides of a volcanic mountain. Altitude 1981 mASL. Common at the lower and drier altitudes.
Ufipa region, Tanzania	Mbizi Forest. A mountain edge on the Rukwa Rift escarpment. Tall forest tree 12–16 m. Also present with fringing vegetation. Dominant upper storey trees include *Entandophragma, Euphorbia, Polyscias*. Lower storey trees include *Dombeya, Croton, Lianes, Toddalia*. Altitude 2286 mASL.
Matthews Range, Samburu region, Kenya	Upland forest on basement complex with *Juniperus, Croton megalocarpus* and *Encephalartos tegulaneus* in drier areas, *Podocarpus gracilis* and *P. milanjiana* in moister areas. Altitude 1752 mASL.
Longonot, Nakuru region, Kenya	One of the commonest trees on lava flows, usually in pockets of soil on the crests of ridges. May be up to 10 m high. Altitude 1951 mASL.
Marafara, Kilifi region, Kenya	Tree 5 m. Coastal thickets with *Combretum hereroense, Terminalia prunioides, Sideroxylon, Thespesia*. Altitude 80 mASL.
Virunga National Park, Semliki River, Dem.Republic of Congo	Woodland on banks of river and grassy plateau just above it. Dominant shrub/tree along much of the river. Associated with *Euclea, Grewia* and *Acacia sieberiana*. Altitude 950 mASL.

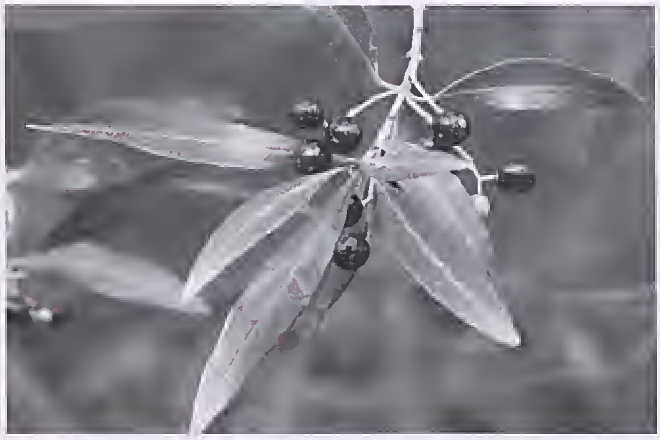


Fig. 1. African Olive fruits (7-10 mm diameter) ripen during winter and are attractive to birds.

habitat attract a range of fruit-eating birds eg. pigeons, parrots, louries, mousebirds, bulbuls and starlings (Venter & Venter 1996). The fruits are also eaten by monkeys, mongoose and humans (Pooley 1993). The leaves are used to make a tea, a gargle for sore throats and an eye lotion (University of Pretoria 2004). Wood produced is close grained, strong and very hard (Palgrave 1983). Due primarily to over exploitation of its useful timber, African Olive is considered threatened in some African regions and is a protected tree in the Northern Cape, Free State and North-west Provinces of South Africa.

History of introduction to Australia

African Olive was first introduced to Australia in the mid 19th century as an ornamental and hedging plant (Muyt 2001) and as a rootstock for the European olive; which later proved to be unsuitable (Spennemann & Allen 2000a). Tracing the general horticultural introduction and use of African Olive in Australia is complicated by the lack of consistent nomenclature, particularly that used in old nursery catalogues, where there is a tendency to group African Olive with the European Olive. African Olive does not produce fruits of commercial value, and is also listed in nursery catalogues as the hedging plant *Wild Olive*.

Olives are recorded as one of the earliest plant introductions to Australia, with European Olive (*Olea europaea*) planted at Elizabeth Farm, Parramatta by the agricultural pioneer John Macarthur in 1805 (Dellow 1987). The introduction of African Olive in the Cumberland Plain region, south west of Sydney (now a major centre of African Olive spread), is closely linked to John Macarthur, and his sons John and William, and the development of the famous *Camden Park* estate, near Camden, in southwestern Sydney. African Olive appears to have been planted as a hedge for the original vineyard, established in the 1820s, and planted specimens, now of great size, and consistent with the original planting layout, are still present at *Camden Park* (C.Mills, pers. comm.)

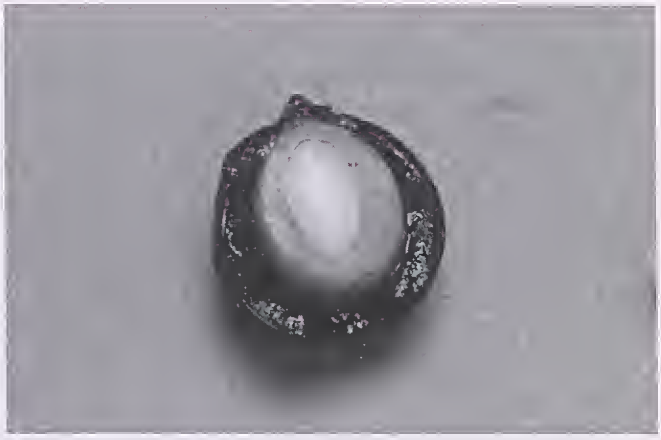


Fig. 2. Birds consume the ripe black African Olive fruits, digesting the fleshy outer covering and voiding the hard woody seed endocarp (3-5 mm diam). The fruit and seed is well within the optimal size range for dispersal by a range of Australian native and introduced bird species.

An established nursery operated at *Camden Park* during the mid 19th century and contemporary catalogues listed many African species that have since become environmental weeds. The Macarthurs' 1843 *Catalogue of Plants Cultivated at Camden* listed '*Olea europaea* (six varieties)' presumably including African Olive under this name. African Olive was extensively planted as a hedge throughout the Camden area; these trees can still be seen at historic properties, lining paddocks and driveways and were an important element of these 19th century 'wilderness' gardens (Landare 1993).

From the 1930s to the 1970s, African Olive was available in the NSW nursery trade as a hardy small tree or hedge plant and is listed in catalogues from leading nurseries such as the NSW Forestry Commission and Swane's. The first indication of the weed potential of African Olive is evident in the 1976 Forestry Commission catalogue which lists *Olea africana* "Golden Olive" as *a useful small tree that withstands a good deal of drought and heat and makes an excellent hedge*; with a warning that *it can become a very bad weed in some areas e.g. Cobbitty (near Camden)* (Forestry Commission 1976). African Olive is no longer grown commercially or widely available in the nursery trade, though the Australian Association of Bush Regenerators list African Olive as a major weed that is still cultivated in gardens near bushland (AABR 2004).

Distribution of African Olive in Australia

African Olive is established as an adaptable and persistent environmental weed in eastern Australia, capable of growing in both temperate and sub-tropical regions. Below is a short summary of the worst areas of infestation.

Western Sydney - NSW

The Camden – Campbelltown area on the southern edge of the Cumberland Plain in western Sydney is the most established centre of African Olive occurrence in Australia. Here historic properties have provided multiple source locations for the spread of African Olive, facilitated by frugivorous birds. It was first noted as a potential problem weed in the area around the mid -1970s, by which it time it formed shrubby thickets on the steeper slopes and hills in the Camden – Cobbitty area, particularly on the Razorback Range (Forestry Commission NSW 1976, D. Benson, pers. comm). By the 1980s it was described as a major invading weed of grazing parkland in the Camden/Campbelltown area (Dellow 1987). The rapid expansion of African Olive in the Camden – Campbelltown area from the 1980s has been documented at Mount Annan Botanic Garden. With the cessation of grazing, African Olive has spread throughout Mount Annan Botanic Garden beginning with scattered occurrences over 20 hectares in 1985 to a present coverage of 80 hectares, with some sections now developed into mature (>15 years age) pure stands on steeper sites. From established populations in south-west Sydney, African Olive is now spreading northwards to other areas of the Cumberland Plain, primarily along roadsides and beneath powerlines into the Penrith and Windsor areas.

The expansion of African Olive in western Sydney is significant, as the region contains thirteen Endangered Ecological Communities listed under the *NSW Threatened Species Conservation Act 1995*. Native vegetation on the Cumberland Plain has been extensively cleared since European settlement, with intact native vegetation now reduced to 13% of the landscape (NPWS 2006). Major African Olive occurrences are mapped for the Camden, Wollondilly, Liverpool, Campbelltown and Penrith local government areas (LGAs) (NPWS 2002), and show a preference for heavily disturbed sites on shale-derived soils with a landslope of >20 degrees (Roberts 1999). African Olive poses a major threat to the long term existence of Cumberland Plain Endangered Ecological Communities, and is specifically noted as a threatening woody weed in the NSW Scientific Committee determinations for Western Sydney Dry Rainforest and River Flat Eucalypt Forest on Coastal Floodplains. Over 1300 ha of dense African Olive understorey has been identified in Cumberland Plain vegetation mapping (NPWS 2002) with substantial infestations occurring in the Endangered Ecological Communities, Cumberland Plain Woodland (985 hectares) and Moist Shale Woodland (208 hectares). Recent mapping of major African Olive infestations throughout the Cumberland Plain using 2000 satellite imagery (P. Cuneo unpublished data) has identified 4000 ha, where African Olive occurs as a dense and dominant understorey.

African Olive occurs as scattered occurrences in the Kurrajong – Grose Vale area and Scheyville National Park. In the Ryde LGA, where African Olive is a declared noxious weed, infestations appear to have originated from historic plantings at Brush Farm, with current spread now limited to several small bushland parks (A. Smith pers. comm.).

Illawarra region , NSW

African Olive is found in the Kiama, Dunmore and Bombo districts (P.Cuneo, pers obs.) and is listed as one of the significant woody weeds that threaten the long-term viability of the listed Illawarra Subtropical Rainforest Endangered Ecological Community (NSW Scientific Committee 2002). Dense infestations of African Olive occur north of Lake Illawarra in the Berkeley Hills area, in conjunction with remnant stands of Illawarra Subtropical Rainforest.

Hunter Region, NSW

African Olive is considered to be one of the most serious environmental weeds in the Central Hunter region, because of its ability to completely alter ecosystems through crowding and shading (Peake 2005). Vegetation mapping for the Central-Upper Hunter region (Peake 2005) describes four Spotted Gum/Box/Ironbark grassy woodland communities of regional conservation significance which are under threat from African Olive. African Olive is considered to be a serious threat to the Lower Hunter Spotted Gum – Ironbark Forest Endangered Ecological Community (Peake 2005). Dry rainforest vegetation in the Upper Hunter region includes native Oleaceae species, which are also at risk from African Olive invasion. Maitland LGA contains a major infestation of African Olive, with an estimated 15 000 hectares (B. Worboys pers. comm.) centred in the Lochinvar – Maitland Vale districts. African Olive infestation in the Maitland area ranges from scattered plants to ~2000 ha of established dense monocultures on hilly terrain. Observations by local government weed control officers confirm that African Olive is now well established, and has spread significantly over the past five years in the Cessnock, Maitland and Port Stephens local government areas. The characteristic distribution and spread of African Olive along roadsides is reported from the Hunter region, particularly where there are overhead powerlines, fencelines and large trees that provide perch sites for birds. Other Hunter region locations include Rothbury, Hinton and Woodville where African Olive densities are low and in the early stages of invasion. (G. Pritchard, B. Shepherd pers. comm.). African Olive also occurs in the riparian zone along the Hunter River (M.R. Leishman pers. obs.), including highly saline creeklines dominated by Swamp Oak (*Casuarina glauca*).

North-western slopes, NSW

African Olive commonly occurs in townships throughout the North-western slopes region (Hosking pers comm.) but has not established as large infestations. Locations for African Olive include Oxley Park, Tamworth and Attunga State Forest (Hosking & James 1998), and Nundle and Woolomin (Lawler pers. comm.).

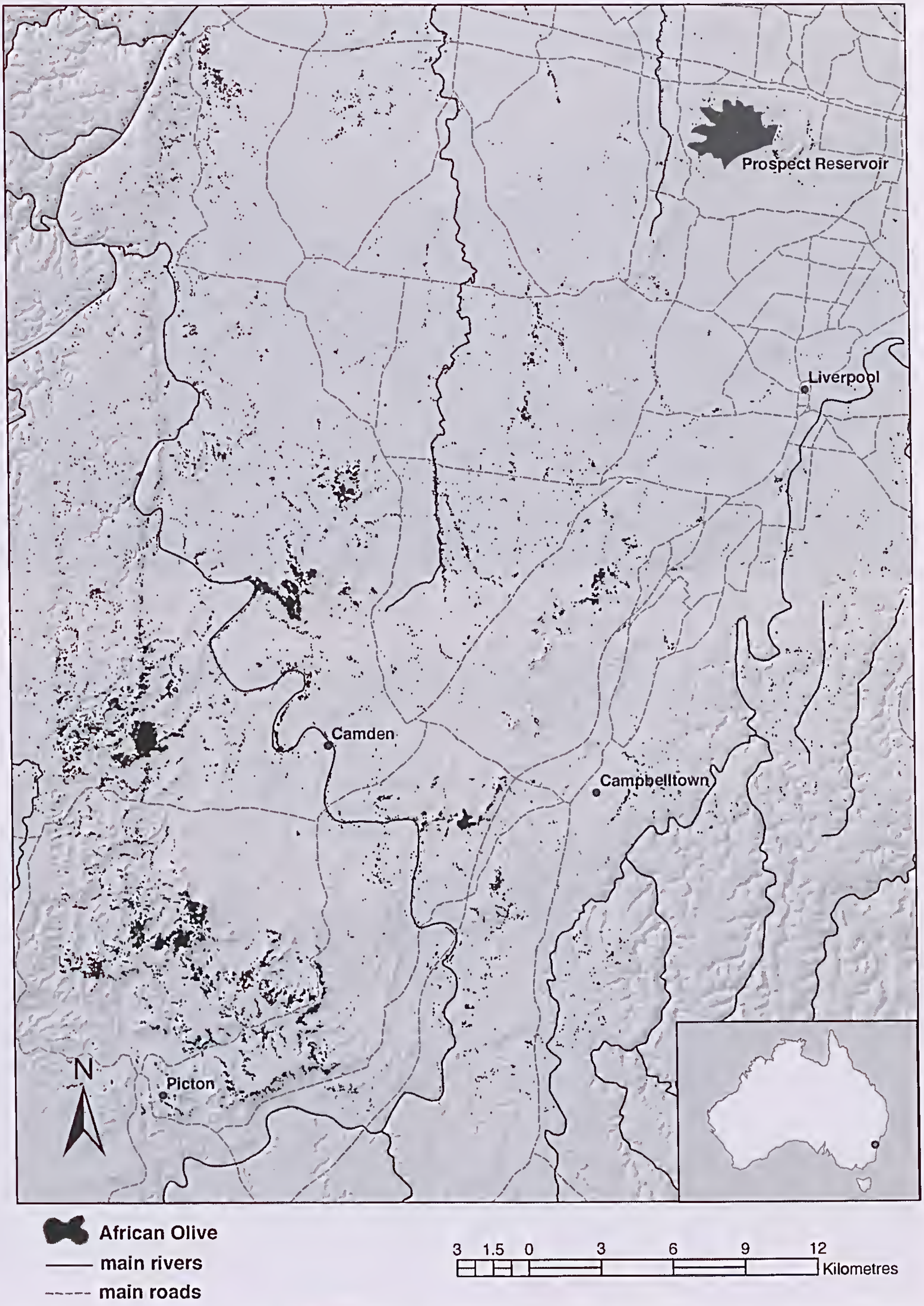


Fig. 3 African Olive is well-established on the clay soils and hilly terrain of south-western Sydney. It is widely established in the Camden region, and has spread rapidly since the 1980s. Dense infestations now threaten fragmented native vegetation. Source: Landsat 2000 imagery

North Coast, NSW

African Olive is reported from dry rainforest in the Wollongbar area near Lismore (D. Bailey pers. comm.). Old specimens of African Olive (estimated to be at least 80 years old) exist at the Agriculture Department site at Wollongbar with some spread of the population into adjacent rainforest remnants (M. Delaney pers. comm.). A single large tree has been recorded in subtropical rainforest at Eltham, but has not yet displayed invasive tendencies.

Norfolk Island

African Olive is one of the worst woody weeds on Norfolk Island, occurring as isolated plants, scattered clumps, and impenetrable thickets (DEH 2004). Norfolk Island was settled by Europeans in 1788 and considerable deforestation occurred soon after (Hill 2002). As the native forest was cleared African Olive became a major weed, and quickly established dense closed monoculture forests. The dense forests of African Olive have impacted on the habitat of the rare Norfolk Island Green Parrot, with African Olive forest supporting the lowest number of nesting sites. However, African Olive seeds may now form a significant part of the diet of newly-fledged juveniles of this species. (Motte & Hall 1988; Davidson 1997). The establishment of African Olive as major woody weed species in the subtropical climate of Norfolk Island (average annual rainfall 1325 mm, range 784–1856 mm) is a clear indication of its adaptability to climatic zones outside current distribution in mainland Australia.

Adelaide Hills, South Australia

African Olive has also become naturalised in the Adelaide Hills region, and is recorded for Shepherds Hill Recreation Park (AVH 2006). However European Olive is much more prevalent, being widely described as the most serious weed in the Adelaide Hills (Muyt 2001). European Olive appears to be better adapted to the Mediterranean climate of the region than African Olive (D. Bass pers. comm). Heavy infestations of European Olive in the Adelaide Hills do not form the same dense continuous canopy that characterises African Olive infestation in NSW (P. Cuneo pers. obs.).

African Olive invasions outside of Australia

Hawaiian Islands

African Olive is naturalised on the islands of Hawaii, Maui and Kaua'i, where it was planted as windbreaks and hedges (Starr et al. 2003). The pattern of introduction and spread is remarkably similar to the spread in Australia. For example, the fruits are readily dispersed by birds, and plants establish along roadsides, disturbed woodlands and pastures from sea level up to 1500 m elevation. African Olive was first collected as a garden escape on the island of Hawaii in 1965. By 1992 it was found on over 6000 ha at the Hawaii Volcanoes National Park; this infestation is thought to have spread significantly following the removal of cattle (Santos, Kageler et al. 1992).

New Zealand

African Olive is listed by the Bay of Plenty Regional Environment Council as a weed of open coastal scrub and modified sites near native forest margins. It occurs on both inshore and offshore islands such as Raoul Island (Kermadec Island group), where it is showing aggressive weed tendencies similar to on Norfolk Island (BPRC 2006). An African Olive eradication program is currently being implemented on Raoul Island by the New Zealand Department of Conservation (Ambrose pers. comm.). Occasional occurrences have been reported around Auckland city and the inner Hauraki Gulf islands where it displaces coastal shrubs and trees (BPRC 2006).

Weed Ecology of African Olive in Australia

Seed development and soil seedbanks

Flower and fruit development for African Olive in Australia closely matches that of European Olive, described by Crossman (2002). Individual African Olive trees produce fruit on a supra-annual cycle of 2–3 years depending on seasonal conditions. Flower initiation commences during late spring (October) with the small (5 mm) creamy white flowers appearing in mid summer (December). Pollination under Australian conditions is not documented, but is considered to be primarily by wind (as for European Olive) and a range of insects. The small green fruits develop during late summer and ripen during winter. Fruits are 6–7 mm in diameter at maturity and change from green to purple-black in colour when ripe. Trees at the early mature stage are capable of producing more than 25 000 fruits (P. Cuneo unpub. data). Fruit maturation within stands is asynchronous, with ripe fruits produced on individual trees from June – September. Baskin and Baskin (1998) report that *Olea africana* (syn. *Olea europaea* subsp. *cuspidata*) seed exhibits morphophysiological dormancy, ie before germination can occur the embryo must grow to a specific size, and the physiological inhibiting mechanism of the embryo must be broken.

Freshly collected African Olive seed has high viability, up to 88% (P. Cuneo unpub. data) and germinates readily following removal of the woody endocarp; however current work at Mount Annan Botanic Garden has not been able to produce consistent germination of intact fruit or extracted seed older than 9 months. Further research is required to determine the way fleshy fruit breaks down and dormancy is overcome, particularly under field conditions. Seed longevity in the soil seedbank is considered to be up to 2 years (von Richter, unpub. data), similar to other Oleaceae genera such as Privet (Panetta 2000). The role ingestion by birds plays in the breakdown of seed dormancy has not been assessed, but

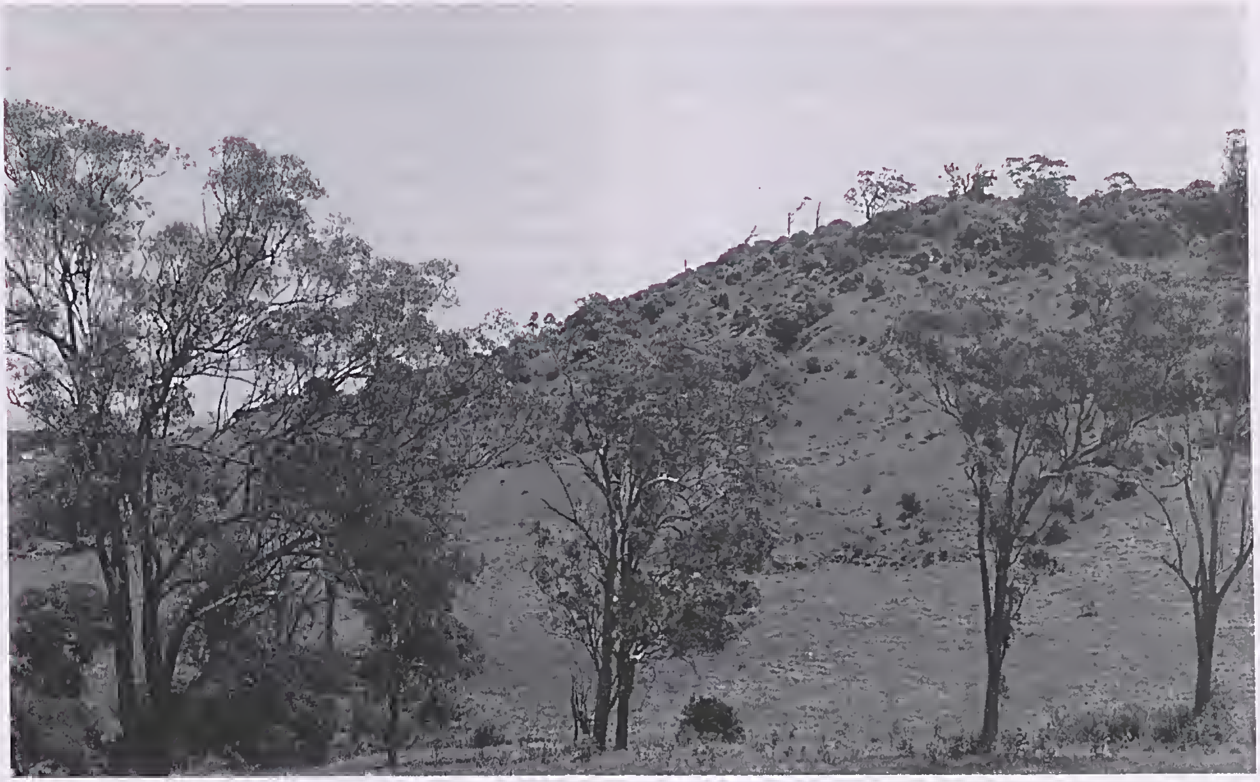


Fig. 4a. The eastern side of Mount Annan in 1984 as a grazing property, with African Olive plants already well-established on the steeper slopes.

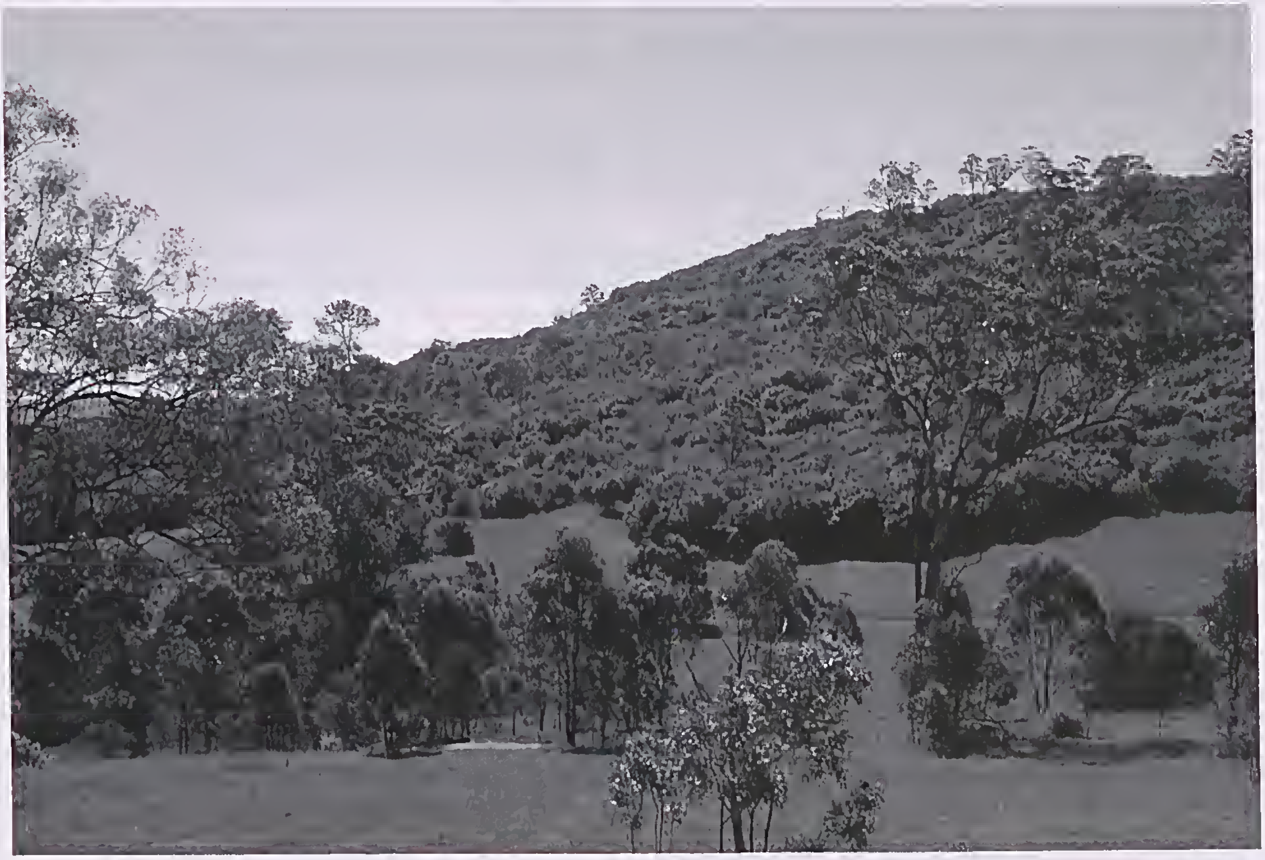


Fig. 4b. The same view in 2004, part of Mount Annan Botanic Garden since 1988, showing increased density and local expansion of African Olive plants. Recruitment of native eucalypts has taken place in the foreground where Olive has been controlled by spot herbicide application and mowing.

there appears to be a clear association between the spread of African Olive and dispersal of its seed by birds, and it is highly likely that removal of fleshy fruit through the bird digestive system assists germination.

Dispersal

Avian seed dispersal is a key characteristic of African Olive spread and establishment as an environmental weed. Birds are attracted to the fleshy black fruits, and seedlings establish under isolated trees used by birds (Benson & McDougall 1999). The fruits provide a nutritional source which could be considered comparable to that of the fleshy pulp of European Olive, which is high in oil content (5%–30%) (Levinson & Levinson 1984). In addition, the fruit is considered an important energy source for birds and small mammals (Spennemann & Allen 2000a). Introduced foxes (*Vulpes vulpes*) also consume significant amounts of African Olive fruits, with up to 142 olive seeds recorded from individual fox scats (L. von Richter unpub. data). Research on dispersal dynamics and establishment of African Olive seed is limited, however the pattern of dispersal where it establishes as seedling "halos" around large perch trees and along fence lines and powerlines is well documented (Spennemann & Allen 2000b, Muyt 2001, Starr 2003), indicating the importance of avian dispersors.

In dietary studies of Pied Currawongs near Sydney Buchanan (1989) found that plants from the Oleaceae family including African Olive and Privet species, *Ligustrum sinense* and *Ligustrum lucidum*, are the most significant part of their diet during the winter months. Long term bird banding studies in a heavy African Olive infestation at Mount Annan Botanic Garden have recorded both native and introduced birds feeding and voiding olive seeds. Native birds observed to eat/consume African Olive seeds at Mount Annan include Silvereye (*Zosterops lateralis*), Golden Whistler (*Pachycephala pectoralis*), Olive-backed Oriole (*Oriolus sagittatus*), Black-faced cuckoo shrike (*Coracina novaehollandiae*), Lewins honeyeater (*Meliphaga lewinii*), Pied Currawong (*Strepera graculina*), while introduced bird species include Red-whiskered Bulbul (*Pycnonotus jocosus*), Common Starling (*Sturnus vulgaris*) and Common Blackbird (*Turdus merula*) (Leishman, A. 2001). Though there is no quantitative data on the seed rain resulting from bird dispersal, Leishman, A. (2001) has recorded Silvereyes voiding up to 16 olive seeds, and a single Olive-backed Oriole voiding in excess of 30 olive seeds at Mount Annan during the holding time (30 minutes) prior to banding. On the Hawaiian Island of Maui, dispersal of African Olive seed by frugivorous birds and subsequent germination up to one mile from cultivated plants has been observed (Starr et al. 2003).

The role of birds in the seed dispersal and subsequent establishment of European olive as a weed is documented in Australia (Spennemann & Allen 2000b, Crossman 2002) and Spain (Alcantara et al. 1997). When cultivated olive groves are abandoned, the fruit of self-seeded olive trees are smaller than the original cultivars, and avian fruit dispersal increases (Spennemann & Allen 2000a) as birds are less able to manipulate and swallow fruits wider than 11.83 mm diameter (Alcantara & Rey 2003). The normal fruit size of ~7 mm for African Olive is well within the optimal size range for dispersal by a wide range of Australian native and introduced bird species. Large seeds are better able to tolerate a range of hazards during establishment than smaller seeds (Leishman et al. 2000), and the relatively large size of African Olive seed is likely to provide a competitive advantage (Leishman, MR 2001), particularly in grassy woodland communities such as in western Sydney, which are dominated by small-seeded herbaceous and graminoid species.

Typical stages of African Olive establishment and environmental impacts

Here we describe a model for African Olive establishment and spread based on observations and archives of African Olive populations at Mount Annan Botanic Garden and in bushland remnants across western Sydney over a 15 year period, and on aerial photo records (PWD 1985, Qasco 1993, Montgomery Watson 2000). Three distinct stages of invasion are recognised — initial invasion, establishment, and mature dense stand.

Initial invasion stage (0–7 years)

African Olive seed is dispersed by birds, and seedlings establish under isolated (or emergent) trees (Benson & McDougall 1999), forming seedling "halos". Some seedlings may establish following bird dispersal into understorey vegetation such as *Bursaria spinosa* thickets. Seedling growth rate is highly variable and dependent on aspect and moisture availability, with plants growing vigorously along creek and drainage lines. Plants in dry, open, exposed sites are commonly less than 1 m high after 5–10 years (D. Benson, pers. comm.). In moist, more protected sites, plants reach sexual maturity after 5–6 years and are commonly shrubs 3–4 m high and 3–4 m wide, with an average stem diameter of 35 mm at this early fruit-bearing age.

After shrubs begin fruiting they develop dense seedling "mats" in the seed fall zone of each plant. Seedling densities of 950 seedlings/m^2 are commonly observed, and seedlings in these dense 'mats' have the capacity to remain suppressed in this 'seedling bank' stage for many years. At the initial invasion stage, African Olive commonly occurs as scattered shrubs with light levels at ground level remaining high, and native shrubs such as *Bursaria spinosa* maintaining a comparable height and density to olives. Native grasses and herbs persist in the initial invasion stage, under the discontinuous olive/native shrub layer, and eucalypt seedling recruitment and sapling growth is still evident.

Establishment stage (8–12 years)

During the establishment stage, African Olive trees reach their full height of 10–13 m forming dense stands of slender single and multi-trunked trees with an average spacing of 1–2 m. Single trunked trees at this stage may have stem diameters averaging 100 mm (DBH), with multi-trunked trees averaging 158 mm. Light levels at the ground layer are now substantially reduced as the olive canopy begins to dominate and shade out native shrubs such as *Bursaria spinosa*. Recruitment of eucalypts is suppressed and olive seedling "mats" thin out to low density etiolated seedlings up to 1m high. Native plant species that favour edge conditions and higher light levels such as *Themeda australis, Austrodanthonia spp, Ajuga australis* and *Aristida vagans*, no longer persist under the increasing shade and root competition from the dense African Olive trees, though shade tolerant and resilient species such as *Dichondra repens, Microlaena stipoides, Brunoniella australis* and *Eremophila debilis* persist underneath olives at this stage. Eucalypt saplings and tall-growing species such as *Acacia implexa* that have maintained an adequate growth rate and height above the olive canopy continue to grow. A distinctive bare soil zone is evident along the margins of established

Table 3: Techniques and registered herbicides for the control of African Olive

Technique	Application/Method	Comments
Cut stump (cut & paint)	Plants are sawn off close to ground level and undiluted Glyphosate 360 g/l (eg,Roundup®) is applied (Ensbey 2004) by brush or applicator bottle (within 30 seconds) to the cambial layer of the stump (APVMA permit 9158). Triclopyr (Garlon 600® - reg label 31898) and diesel mixture (1:14) (Ensbey 2004) is also highly effective as a "cut and paint" application (Dellow 1987),	Plants growing in damp areas or treated during dry conditions may require special attention as they may re-shoot (National Trust 1999).
Foliar Spray	Spray control of seedlings and coppice shoots using Glyphosate 360g/l diluted at 1:75 or 1:100 rate (Ensbey 2004) (APVMA permit 9158).	Effectiveness is highly variable. Ziesing (1997) reports increased effectiveness in seedling control with the addition of Urea in spray tank.
Tree injection	Portable drills are used to drill 3 cm deep holes into the trunk at a 45 degree angle, spaced 4 cm apart. Undiluted Glyphosate 360 g/l at a rate of 2.5 ml per hole is injected into each hole using an applicator bottle or backpack injection unit (APVMA permit 9158). Frilling technique is similar, with chisels used instead of portable drills to create an opening at regular intervals in the trunk for the injection of glyphosate.	This is commonly used to control African Olive in inaccessible areas, such as olive "halos" around large Eucalypt perch trees, where cutting and removal of material is not practical. African Olives are left in situ and can be useful in maintaining temporary habitat for small native birds.
Basal bark spray	Garlon® (Triclopyr) diluted in diesel oil applied to the first 30 cm of trunk, wetting the bark to runoff point. In NSW & SA, Garlon® is registered for use on Olive as both a cut stump and basal bark application at a rate of 1:14 with diesel oil (Reg label 31898).	Simple-to-apply technique, outstanding in controlling olive regardless of size (Dellow 1987). Cost effective, but best done by experienced personnel with spray equipment fitted with Viton® seals (resistant to mineral oils). Care is required to prevent soil contamination in bushland areas.
Fire	Young olive plants <1 metre are killed by low intensity fire (von Richter et al 2005)	Mature African Olive trees can be controlled by fire when individual cut stumps are exposed to intense heat produced by large pile burns placed on top. (P. Dixon, pers. comm).
Physical removal/cultural	Seedlings can be hand pulled at the <10 cm stage, which is best done during moist soil conditions. African Olive is palatable to stock, who effectively control the development of young seedlings. In agricultural situations, African Olive is readily controlled by increasing grazing pressure (Parsons & Cuthbertson 1992).	
Mechanical removal	Mechanical control of mature plants with drum mulcher (attached to excavator) has been used where access is available and erosion hazard is low.	Highly effective for large scale infestations, provided African Olive trees and seedlings are treated with herbicide prior to mechanical mulching. Mulched material maintains soil cover.

stage African Olive stands, beyond the tree crown, but it is not known whether the development of a dense African Olive crown has an allelopathic effect on native species, similar to that described for weedy European Olives in Australia (Plant & Animal Control Commission 2006).

Mature dense stand stage (15 years +)

As African Olive establishes mature dense stands over 15 years or longer, the vegetation structure changes towards a more uniform stand dominated by multi-trunked trees with an open understorey. Individual trees are large and commonly multi-trunked close to ground level, with an average diameter (DBH) of 338 mm. The crowns of these mature trees are dense and spreading, forming a continuous canopy 15–18 m high. Only older emergent Eucalypts are able to survive above the African Olive canopy. At this stage African Olives have an average spacing of 6–8 m, with light levels at the ground level now sufficiently low that olive seedlings are suppressed. Most native seedlings are suppressed under the dense canopy, with only highly shade tolerant species such as Maidenhair fern, *Adiantum aethiopicum*, and the climber, *Cayratia clematidea,* persisting under the dense canopy. The margins of mature dense stands receive higher light levels and are occupied by smaller, densely-branched Olives averaging 5 m in height, with dense seedling 'mats' of Olive seedlings.

Fire response

African Olive regenerates readily from a lignotuber structure at the base of the trunk after fire, in a similar manner to the native shrub *Bursaria spinosa* with which it commonly co-occurs in the Sydney region. African Olive seedlings up to 1 m high are killed by low intensity fire (von Richter et al. 2005).

Environmental conditions and impacts

African Olive appears to tolerate a wide range of environmental conditions and is able to establish in temperate or subtropical environments. African Olive is able to establish on steep, exposed hilly terrain well beyond the tolerance of related woody weeds such as Privet (*Ligustrum* spp). The southern Cumberland Plain is an area of low rainfall in the Sydney Basin (Camden – 828 mm, Bureau of Meteorology 2006), and African Olive has successfully established in most plant communities and aspects in this undulating, hilly terrain.

The high resin content of leaves and stems is a contributing factor to its ability to withstand the climatic extremes of exposed, west-facing slopes and ridgelines on poorly-developed soils. On the southern Cumberland Plain, African Olive shows a strong preference for clay-based soils derived from Wianamatta Shale, with seedling and mature plant establishment in adjacent Hawkesbury Sandstone areas only sporadically observed around perch trees. The large seed size of African Olive suggests that it can tolerate a broad range of establishment hazards such as shade, low soil moisture, herbivory and competition. Cooke (2001) showed that soil beneath African Olive canopy had elevated pH and available phosphorus, but not to the extent of Privet (*Ligustrum* spp) which was associated with phosphorus levels five times that of soil associated with native vegetation.

The establishment of African Olive along roadsides and exclusion of native species has a significant impact on native plant diversity, as roadsides are often the last refuge for understorey species that have been lost through grazing and clearing of adjacent properties. The establishment of African Olive to the mature canopy stage permanently changes ecological function and landscape identity by dramatically reducing native plant diversity.

Noxious weed declarations and control techniques

African Olive is currently a declared Class 4 noxious weed under section 7 of the NSW Noxious Weeds Act 1993 for the Ryde LGA. The control objective for class 4 weeds is to minimise the negative impact of those plants on the economy, community or environment of NSW (NSW Government 2005). As a Class 4 weed in the Ryde LGA, the growth and spread of African Olive must be controlled according to the measures specified in a management plan published by the local control authority and the plant may not be sold, propagated or knowingly distributed (NSW DPI 2006). In view of the current African Olive infestation and spread in regions such as western Sydney there is clearly a need for a review of its declaration as a noxious weed beyond the Ryde LGA. The recent declaration of Privet (*Ligustrum lucidum* and *L.sinense*) as a Class 4 weed in seven western Sydney LGAs presents an opportunity for the co-management of both Privet species and African Olive in the development of Class 4 weed management plans.

In South Australia, Olive (all subspecies of *Olea europaea*) are listed as a Class 5d weed under the Natural Resources Management Act 2004. Under the provisions of this Act, an owner of land within a control area for a class of plants to which this subsection applies must control and keep controlled all plants of that class on that land (Parliament of South Australia 2004). For Class 5d weeds, landowners may also be liable for the cost of roadside weed control measures adjacent to their property.

There are no known biological control agents used in the control of African Olive in Australia. Olive Lace Bug (*Frogattia olivinia*) is native to NSW and southern Queensland and has potential as a biological control agent for weedy *Olea* species. Olive Lace Bug is known as a pest of European Olive (WA Agriculture 2004) and has established widely on weedy European olives in South Australia, causing small olive fruits on heavily infected trees to fall before ripening (Robertson 2005). Olive Lace Bug has not been noted as impacting on African Olive, and research is required to determine if it could provide a level of biological control. With the rapid growth of the olive industry in Australia in recent decades, any move to introduce a biological control agent for African Olive is likely to encounter strong industry resistance.

Conclusions and recommendations

African Olive is a highly persistent and adaptable environmental weed now well-established in eastern Australia. Although part of the *Olea europaea* complex, African Olive is part of a tropical wild olive group, and has a weed ecology that is distinct from European Olive. Distributional data show that African Olive has been able to invade a wide range of habitats ranging from temperate regions with about 800 mm rainfall through to subtropical zones which receive 1200 mm annual rainfall. Its rate of spread in south-western Sydney and the Hunter Valley clearly indicate that this species can no longer be considered a 'sleeper' weed. In the Sydney region, African Olive has the ability to establish on dry exposed ridgelines, yet is also able to grow in conjunction with other woody weeds in the *Oleaceae* such as Privet (*Ligustrum spp*), on high soil moisture and fertility sites.

African Olive invasion leads to a loss in native plant diversity, and research into restoration ecology is needed, particularly for sites with an established cover of African Olive where bush regeneration, and cutting and poisoning are the main methods of control. There is a need for further research into the persistence of African Olive seed in the soil seedbank, and the process by which seed dormancy is overcome. As avian dispersal is a key factor in African Olive seed dispersal, the role of frugivorous birds in promoting seed germination needs to be further understood. Key aspects of restoration ecology would include an investigation of an apparent allelopathic effect observed under dense olive stands, the role of shade in suppressing other plant species, and the use of fire to kill immature plants and stimulate the native soil seed bank.

At the landscape scale, the current distribution of African Olive in eastern Australia should be accurately mapped, and a weed awareness strategy developed and implemented across affected local government areas. GIS and satellite imagery offer the potential to complete coarse scale mapping based on the distinctive reflectivity and texture of African Olive. Modelling of potential for African Olive spread should also be undertaken, based on current distributional data and habitat preference.

There is a strong case for African Olive to be declared a noxious weed throughout western Sydney and the Hunter Valley regions, and co-managed with Privet (*Ligustrum* spp) under Class 4 weed control plans. A re-evaluation of the most effective control techniques, including currently registered herbicides, is also required.

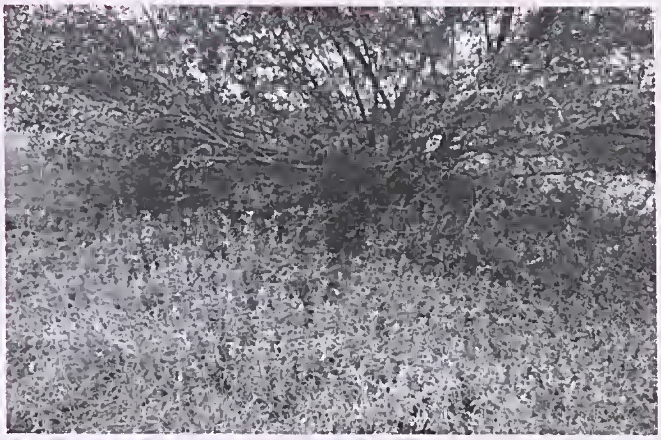


Fig. 5. Dense seedling 'mats' form in the seed-fall zone around mature African Olive plants – providing a 'seedling bank' for future recruitment.

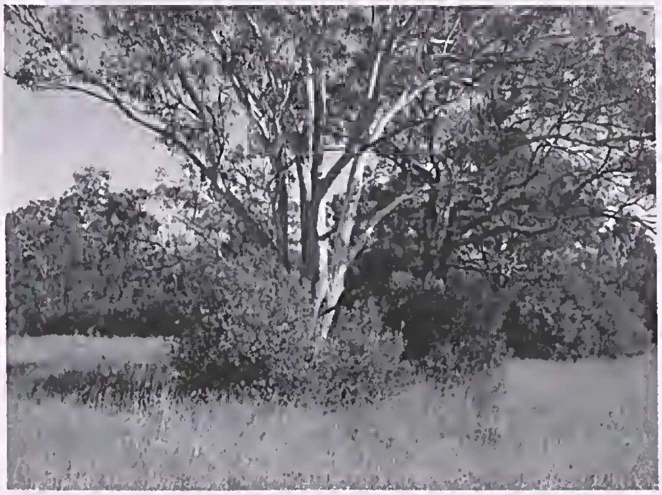


Fig. 6. Birds deposit the woody seed endocarp under perch trees - providing a source point for African Olive infestation.

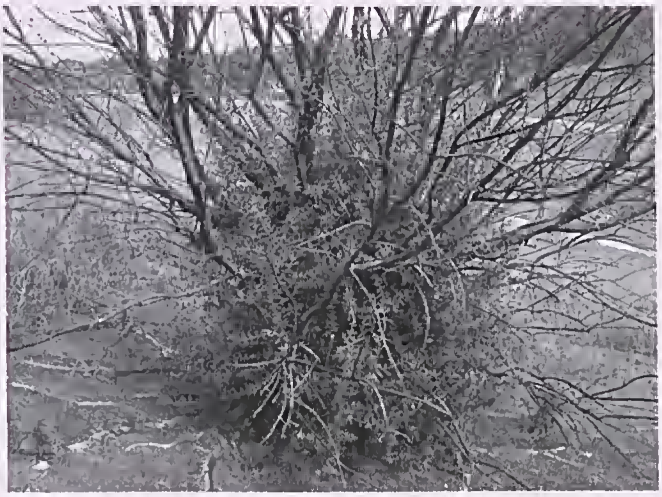


Fig. 7. Mature African Olive resprouting 18 months after fire; seedlings and young plants less than about a metre high are generally killed by fire.

Acknowledgements

We would like to thank Botanic Gardens Trust staff, Lotte von Richter, Doug Benson and Debra Little who have provided valuable insight and observations on the weed ecology and control of African Olive, and the staff and bush regeneration volunteers at Mount Annan Botanic Garden. We also thank Alan Leishman for data on avian seed dispersal, Carol Jacobson (Macquarie University) for advice in GIS mapping, the East African Herbarium for data on natural distribution and Colin Mills for information on early horticultural introductions.

References

AABR (2004). Australian Association of Bush Regenerators: website.
http://www.aabr.org.au/aabr/index.php?option=com_content&task=view&id=52&Itemid=75

Australia's Virtual Herbarium (2006) Records from the State Herbarium of South Australia — *Olea europaea* ssp *cuspidata* http://www.anbg.gov.au/avh/

Alcantara, J.M. & Rey, P.J. (2003). Conflicting selection pressures on seed size: evolutionary ecology of fruit size in a bird-dispersed tree, Olea europaea. *Journal of Evolutionary Biology* 16(6): 1168–1176.

Alcantara, J. M., Rey, P.J., Valera, F., Sanchez-Lafuente, A. M. & Gutierrez, J. E. (1997) Habitat alteration and plant intra-specific competition for seed dispersers. An example with Olea europaea var. sylvestris. *Oikos* 79(2): 291–300.

Baskin, C.C. & Baskin, J.M. (1998) *Seeds — Ecology, Biogeography and Evolution of Dormancy and Germination*

Benson, D.H & McDougall, L. Ecology of Sydney plant species Part 7a, *Cunninghamia* 6 (2): p 421.

Bay of Plenty Regional Council (2006) Environment Bay of Plenty Regional Council, Weed Index — Olive (*Olea europaea* subsp. *africana*) http://www.envbop.govt.nz/weeds/weed310.asp

Buchanan, R. A. (1989) Pied Currawongs (*Strepera graculina*): their diet and role in weed dispersal in suburban Sydney, New South Wales. *Proceedings of the Linnean Society of New South Wales* 111: 241–255.

Bureau of Meteorology (2006) Climatic averages for Australian sites, Site no. 068192 Camden Airport AWS, http://www.bom.gov.au/climate/averages/tables/ca_nsw_names.shtml

Cooke, J. (2001) Impact of Privet (*Ligustrum lucidum*) and Olive (*Olea europaea*) on the regeneration of Cumberland Plain Woodland species. (Centre for Plant Biodiversity Research. Canberra).

Crossman, N. D. (2002) The impact of the European olive (*Olea europaea* L. subsp.*europaea*) on grey box (*Eucalyptus microcarpa* Maiden) woodland in South Australia. *Plant Protection Quarterly* 17(4): 140–146.

Csurches, S. & Edwards, R. (1998) Potential Environmental Weeds in Australia, (Environment Australia, Canberra).

Davidson, P. M. (1997) Movements and Behaviour of Juvenile Green Parrots determined by Radio-tracking. Unpub. report (Environment Australia, Canberra).

Department of Agriculture, Western Australia (2004) *Farmnote No 82/2003 Olive Lace Bug* (*Frogattia olivinia*)
http://www.agric.wa.gov.au/pls/portal30/docs/FOLDER/IKMP/PW/INS/PP/HORT/FN082_2003.PDF

Department of Environment & Heritage (2004). What the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) means for Norfolk Island. Attachment 4 Principal weed species on Norfolk Island. Canberra. http://www.deh.gov.au/biodiversity/publications/norfolk-island/attachment4.html#african

Dellow, J. J., M.Sargeant, S, Rose. (1987) Control of *Olea* spp. *Proceedings of the Eighth Australian Weeds Conference*, (Weeds Society of NSW. Sydney NSW).

Earth Resource Analysis Pty Ltd (1999). *Cumberland Plain Woodland Recovery Plan — Air photo interpretation and data capture*, Vegetation mapping report prepared for NSW National Parks and Wildlife Service. Melbourne, Victoria

Ensbey, R. (2004) *Noxious and Environmental Weed Control Handbook 2004–2005*: 29. (NSW Agriculture : Orange NSW).

Forestry Commission NSW (1976) *Trees for New South Wales*, NSW Forestry Commission. Sydney NSW.

Green, P. S. (2002) A revision of Olea L. (Oleaceae). *Kew Bulletin* 57: 91–140.

Green, P. S. & Wickens, G. E. (1989) The *Olea europaea* complex. In Tan.K. (ed.), *The Davis & Hedge Festschrift*: pp 287–299. (Edinburgh University Press, Edinburgh).

Harden, G. J. (1992) (Ed.). *Flora of New South Wales*, Volume 3, p 472 (New South Wales University Press: Kensington).

Hill, R. (2002) Recovery Plan for the Norfolk Island Green Parrot *Cyanoramphus novaezelandiae cookii. Environment Australia, Canberra*,http://www.deh.gov.au/biodiversity/threatened/publications/recovery/norfolk-green-parrot/index.html

Hosking, J.R. & James, T.A. (1998) Native and exotic flora of the North Western Slopes upstream of the junction of the Peel and Namoi Rivers, New South Wales. *Cunninghamia* 5(3): 721–766.

Landarc Landscape Architects (1993). *Camden Significant Trees and Vegetated Landscape Study*, Vol 3. Report prepared for Camden Municipal Council, Sydney NSW.

Leishman, A. (2001) Fruit dispersal of African Olive by birds, Unpublished report to Mount Annan Botanic Garden, Mount Annan, NSW.

Leishman, M. R. (2001) Does the seed size/number trade-off model determine plant community structure? An assessment of the model mechanisms and their generality. *Oikos* 93(2): 294–302.

Leishman, M.R., Wright, I.J., Moles, A.T. & Westoby, M. (2000) The evolutionary ecology of seed size. In *Seeds — the ecology of regeneration in plant communities* (ed. M. Fenner), pp 31–57. 2nd edition. (CAB International, Wallingford).

Levinson, H. Z. & Levinson, A. R. (1984) Botanical and chemical aspects of the olive tree with regards to fruit acceptance by Dacua oleae (Gmelin) and other frugivorous animals. *Zeitschrift fur angewandte Entomologie* 98: 136–149.

Motte, K. & Hall, E. (1988) *Report and Recommendations on the Green Parrot Cyanoramphus novaezealandiae cookii Captive Breeding Program*. Taronga Zoo, Sydney NSW.

Montgomery Watson Pty Ltd (2000) GIS Data Capture Project — Mount Annan Botanic Garden, digital dataset and unpublished report for the Royal Botanic Gardens, Sydney.

Muyt, A. (2001) *Bush Invaders of South East Australia* — a guide to the identification and control of environmental weeds in south eastern Australia. (RG and FJ Richardson, Meredith, Victoria).

National Trust of Australia — NSW (1999) *Bush Regenerators' Handbook*. (National Trust of Australia. Sydney NSW).

NSW Department of Primary Industries (2006) Noxious Weeds listings for NSW. http://www.dpi.nsw.gov.au/agriculture/noxweed

New South Wales Government (2005) Noxious Weed Act 1993 Weed Control Order No. 19. *New South Wales Government Gazette Special Supplement No 166*: 11671. NSW Government Sydney NSW.

NSW National Parks & Wildlife Service (2002) Native Vegetation of the Cumberland Plain — Vegetation Maps (New South Wales National Parks and Wildlife Service: Hurstville NSW).

NSW National Parks & Wildlife Service (2006) Recovery planning for the Cumberland Plain's Endangered Ecological Communities (New South Wales National Parks & Wildlife Service: Hurstville NSW) http://www.nationalparks.nsw.gov.au

NSW Scientific Committee (2002). Illawarra subtropical rainforest in the Sydney Basin Bioregion — Endangered Ecological Community listing under the Threatened Species Conservation Act 1995 — final determination, http://www.nationalparks.nsw.gov.au

Palgrave, K. C. (1983) *The Trees of Southern Africa*. (C.Struik. Capetown, South Africa),

Panetta, F. D. (2000) Fate of fruits and seeds of *Ligustrum lucidum* maintained under natural rainfall or irrigation. *Australian Journal of Botany* 48: 701–705.

Parliament of South Australia (2004) Natural Resources Management Act 2004 , Part 2 Division 1 Section 185. http://www.parliament.sa.gov.au/Catalog/legislation/Acts/n/2004.34.un.htm

Parsons, W. T. & Cuthbertson, E.G. (1992) *Noxious weeds of Australia*. (Inkata Press: Melbourne).

Peake, T. C. (2005) *The Vegetation of the Central Hunter Valley, New South Wales. A Report on the Findings of the Hunter Remnant Vegetation Project. Final Draft Version 1*. (Hunter — Central Rivers Catchment Management Authority. Paterson, NSW).

Plant & Animal Control Commission — South Australia (2006) *Submission to Senate inquiry into the regulation, control and management of invasive species and the Environment Protection and Biodiversity Conservation Amendment (Invasive Species) Bill 2002*. http://www.aph.gov.au/Senate/committee/ecita_ctte/invasive_species/submissions/sub15.doc

Pooley, E. (1993) The Complete Field Guide to the Trees of Natal, Zululand and Transkei. (Natal Flora Publications. Durban, South Africa).

Public Works Department of NSW (1985) Mount Annan Botanic Garden Project, 1:4000 scale Orthophoto map of Mount Annan Botanic Garden, March 1985, Sydney NSW.

Qasco Pty Ltd (1993) Aerial Photography — Mount Annan Botanic Garden, 1:4000 scale. 22nd November 1993, Sydney NSW.

Robertson, E. (2005) Welcome the Olive Lace Bug. *WeedWise* Volume 6, Issue 2 June 2005. Weed Management Society of South Australia, Torrens Park, South Australia.

Santos, G. L., Kageler, D., Gardner, D.E, Cuddihy, L.W, & Stone, C.P. (1992). Herbicidal Control of Selected Alien Plant Species in Hawai'i Volcanoes National Park. In *Alien Plant Invasions in Native Ecosystems of Hawai'i: Management and Research*. Stone,C.P., Smith.C.W, & Tunison, J.T. (Eds) pp 341–342. (University of Hawai'i Press. Honolulu).

Spennemann, D. H. R. & Allen, L. R. (2000a) Feral olives (*Olea europaea*) as future woody weeds in Australia: a review. *Australian Journal of Experimental Agriculture* 40(6): 889–901.

Spennemann, D. H. R. & Allen, L. R. (2000b) The avian dispersal of olives *Olea europaea*: implications for Australia. *Emu* 100(4): 264–273.

Starr, F., Starr, K. & Loope, L. (2003) *Olea europaea* subsp *cuspidata — African Olive, Oleaceae* — Report by Biological Sciences Resources Division, United States Geological Survey, Maui Hawaii. http://www.hear.org/Pier/pdf/pohreports/olea_europaea_subsp_cuspidata.pdf

Tozer, M. (2003) The native vegetation of the Cumberland Plain, western Sydney : systematic classification and field identification of communities. *Cunninghamia* 8(1): 1–75.

Turcek, F. J. (1963) Colour preference in fruit and seed-eating birds.In *Proceedings of the XIIIth International Ornithological Congress*. Sibley,C.G (Ed). pp 285–292. (American Ornithologists' Union, Baton Rouge, Louisiana).

University of Pretoria (2006) *University of Pretoria Botanical Garden species list* (No 28 *Olea europaea* subsp *africana*) http://www.up.ac.za/academic/botany/garden/species/28.html

Venter, J. A. & Venter. F. (1996) *Making the most of indigenous trees*. (Briza Publications: Pretoria, South Africa)

von Richter, L., Little, D. & Benson, D.H. (2005) Effects of low intensity fire on the resprouting of the weed African Olive (*Olea europaea* subsp. *cuspidata*) in Cumberland Plain Woodland, Western Sydney. *Ecological Management and Restoration* 6 (3): 230–232

Ziesing, P. (1997) *Norfolk Island Weed Control Manual*, (Environment Australia — Biodiversity Group, Norfolk Island, South Pacific).

Zohary, D. (1995). Olive, *Olea europaea* (*Oleaceae*). *Evolution of crop plants*. Smartt, J. & Simmonds, N.W. (Eds) (Longman Scientific & Technical, Harlow, England).

Manuscript accepted 9 August 2006

Distribution and diversity of exotic plant species in montane to alpine areas of Kosciuszko National Park

*Roxana Bear, Wendy Hill and Catherine M. Pickering**

School of Environmental and Applied Sciences, Griffith University, PMB 50 Gold Coast Mail Centre, Queensland 9726, AUSTRALIA.
*Corresponding author email c.pickering@griffith.edu.au

Abstract: Diversity and distribution of exotic plant taxa in Kosciuszko National Park in south-eastern Australia were reviewed based on 1103 records of exotics from 18 vegetation surveys conducted between 1986 and 2004. 154 taxa from 23 families were recorded in the alpine to montane zones, with eleven taxa in the alpine, 128 taxa in the subalpine and 69 taxa in the montane zone. Nearly all taxa were associated with anthropogenic disturbance with only four taxa exclusively recorded in natural areas. 62 taxa were recorded from subalpine ski resort gardens, and although not recorded as naturalised in the vegetation surveys, their presence in the Park is a concern.

Road verges provided habitat for numerous exotics (65 taxa). 44 taxa were recorded in both disturbed and natural locations but most were uncommon (33 taxa < 2% frequency). Nine common taxa *Acetosella vulgaris, Achillea millefolium, Agrostis capillaris, Anthoxanthum odoratum, Cerastium* spp., *Dactylis glomerata, Hypochaeris radicata, Taraxacum officinale* and *Trifolium repens* comprised 68% of records. These species are common to disturbed areas in other areas of Kosciuszko National Park, NSW and worldwide. The forb *Acetosella vulgaris* was the most ubiquitous species particularly in natural areas where it was recorded at 36% frequency. Based on the data presented here and a recent review of other data sets, there are at least 231 exotic taxa in the Park (including exotics in gardens). The increasing diversity and abundance of exotics is a threat to the natural values of this Park.

***Cunninghamia* (2006) 9(4):559–570**

Introduction

Mountain regions are biodiversity hot spots, with alpine regions worldwide estimated to have 8 000–10 000 plant species, around 4% of identified higher plants (Körner 1999). A high proportion of native taxa in mountain regions is endemic (Körner 1999). For example in the alpine area around Australia's highest mountain (Mt Kosciuszko, 2228 m elevation) in south-eastern Australia, 10% of the 212 native ferns and flowering plants are endemic to that alpine area (Costin et al. 2000).

There is widespread agreement that exotic plants pose a threat to natural areas, by competing with natives for light, space and nutrients, and modifying the natural functioning of the ecosystem (Blossey 1999, Prieur-Richard & Lavorel 2000, Williams & West 2000). Community composition and structure may change, affecting availability of food and shelter for native fauna (Adair 1995). Exotic plants may pose a serious threat to the biodiversity and values of native vegetation (Adair 1995), and their increasing diversity and abundance in mountain conservation reserves is of concern.

The diversity and abundance of exotic plant taxa in mountain regions is increasing principally as a result of human activities (Mallen-Cooper 1990, McDougall & Appleby 2000, Johnston & Pickering 2001, McDougall 2001, Godfree et al. 2004, McDougall et al. 2005), and increases in diversity and abundance of exotics in the Australian Alps including Kosciuszko National Park in the last 150 years highlight this pattern. Deliberate and accidental introduction of many species occurred during the exploitation of the high country during the grazing era from the 1830s to 1944 in the alpine zone, and for some 15–20 years longer (i.e. up to the 1960's) in the subalpine and montane area (Helms 1893, Costin 1954, Mallen-Cooper 1990, Good 1992a,b). Rehabilitation of damaged soils and vegetation following cessation of grazing has been another major source of exotic species introductions (Mallen-Cooper 1990, McDougall et al. 2005). Construction and maintenance of the large Snowy Mountains Hydro-Electric Scheme, including some 2000 km of access roads and tracks, buildings, dams and soil piles have resulted in introduction and spread of exotics (Mallen-Cooper 1990). More recently, increased use of Kosciuszko National Park for tourism, including the construction of tourism infrastructure, has contributed to increased diversity of exotic species, including around ski resorts (Mallen-Cooper 1990, Johnston & Pickering 2001, Pickering et al. 2002).

Diversity of exotic plants in Kosciuszko National Park decreases with increasing altitude, due in part to increasing severity of climatic conditions at higher altitudes (Mallen-

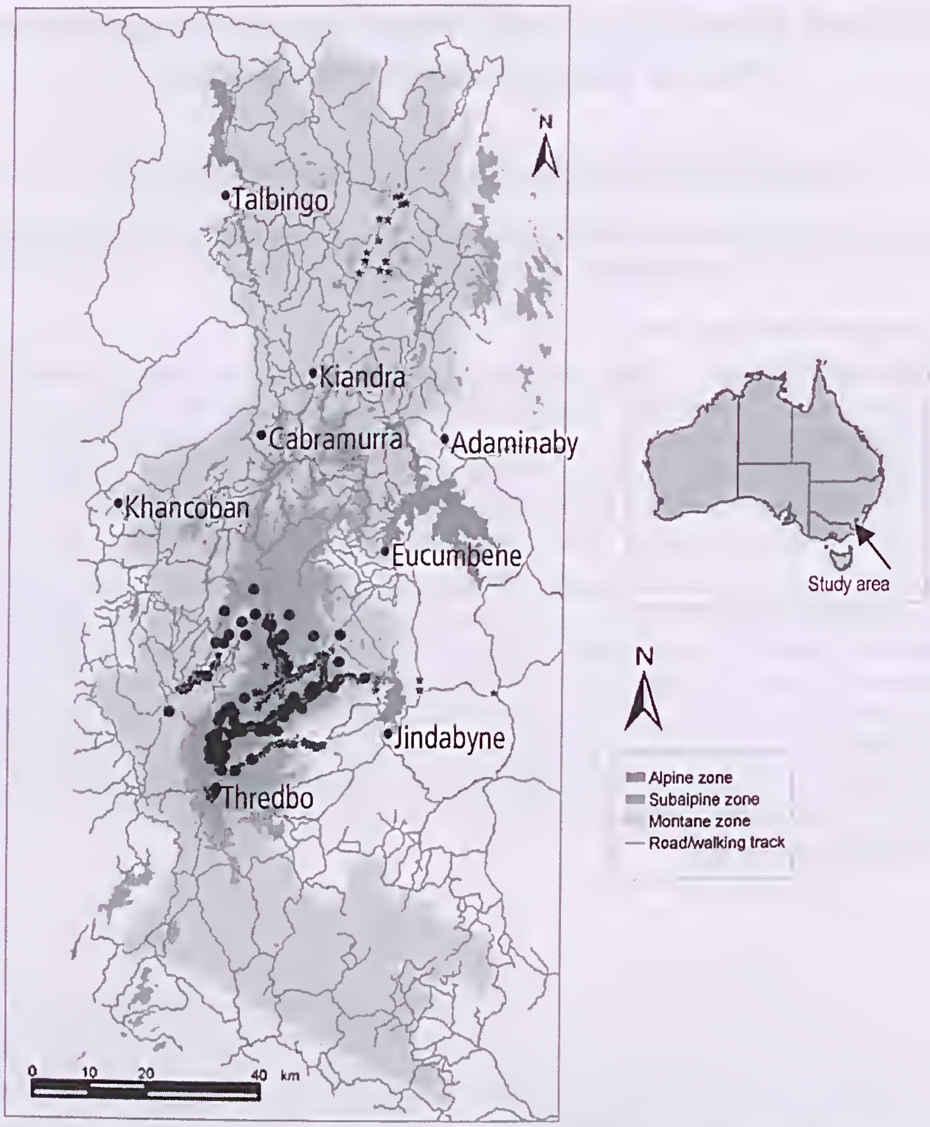


Fig. 1. Location of the 499 sites surveyed in 18 vegetation surveys (1986 to 2004) in alpine to montane zones of Kosciuszko National Park. Sites with exotic taxa and those with only native species are marked.

Cooper 1990, Costin et al. 2000, Johnston & Pickering 2001, McDougall et al. 2005). Many exotics are unable to survive the effects of frost and snow (Mallen-Cooper 1990), while the shorter growing season in alpine areas may prevent exotic seedlings from establishing and growing to reproductive maturity. The structure of native vegetation may also influence invasion by exotic plants, with the discontinuous canopy and patchy understorey of some *Eucalyptus* forests in the montane zone being more susceptible to colonisation than the almost complete vegetative cover that occurs in many alpine and subalpine communities (Mallen-Cooper 1990).

The high conservation values of the Australian Alps, including Kosciuszko National Park, are acknowledged both nationally and internationally (Good 1992a,b, ISC 2004), and the increasing threat posed by exotic plants is recognised (ISC 2004). To obtain a more comprehensive measure of the diversity and distribution of exotic species in the montane to alpine zones of Kosciuszko National Park, existing records from 18 published and unpublished vegetation surveys were collated and analysed. This included comparing diversity and frequency of exotics between areas affected by human disturbance and areas with natural vegetation.

Methods

Kosciuszko National Park Covering approximately 690 000 ha is located in the Snowy Mountains region of the Great Dividing Range between latitudes 33° and 35° south. It is the largest national park in the Australian Alps and one of the largest conservation reserves in Australia (NPWS 2004), with a diverse assemblage of plant communities including many endemic species (Costin et al. 2004). Within the Park there are three main floristic zones — montane, subalpine and alpine - strongly correlated with altitudinal/climatic gradients (Costin 1954, Good 1992b), though some vegetation communities may occur outside 'defined' altitudinal ranges under specific micro-climatic conditions.

The montane zone occurs from approximately 500 m to 1500 m (Good 1992b) and is dominated by *Eucalyptus pauciflora* alliance woodlands in association with other *Eucalyptus* species (*E. delegatensis*, *E. bicostata*, *E. glaucescens* and *E. fastigata*) (Good 1992a,b). Dams, powerlines, buildings and the maintenance of sealed and gravel access roads associated with the hydroelectric scheme are the primary sources of anthropogenic disturbance in the montane zone (ISC 2004).

The subalpine zone occurs from the lower winter snow line at approximately 1500 m to the climatic limit of tree growth at 1850 m (Costin 1954). Winter temperatures average 0°C with a diurnal range of approximately -5°C to 2°C (Happold 1998) and snow cover is continuous for at least one month per year (Green & Osborne 1994). The dominant vegetation is *Eucalyptus niphophila* woodland interspersed with areas of bog, fen, heath and grasslands (Good 1992a,b, Costin et al. 2000). Visitor traffic (vehicular, skiing and walking), ski resort infrastructure and maintenance of roads and ski slopes are major sources of disturbance (ISC 2004).

The alpine zone occurs from the climatic treeline at approximately 1850 m to the top of Australia's highest mountain, Mt Kosciuszko at 2228 m and covers an area of approximately 250 sq. km (Costin et al. 2000). Australia's largest contiguous alpine area is in the park, around Mt Kosciuszko and covers about 100 sq. km (Costin et al. 2000). Annual precipitation ranges from 1800 mm to 3100 mm in the alpine zone, about 60% of which falls as snow, and persists for more than four months in some areas (Green & Osborne 1994). Low-growing shrubs, grasses and forbs characterise the alpine zone and occur in a number of different communities according to the biotic and abiotic characteristics of a site. The primary areas of current disturbance in the alpine zone are gravel access roads and gravel, paved and informal walking tracks (Worboys & Pickering 2002).

Database of exotic plants in Kosciuszko National Park

Exotic taxa recorded in 18 general vegetation surveys undertaken between 1986 and 2004 in the alpine to montane zones of Kosciuszko National Park were collated. Data sources include published research papers, PhD and Honours theses, NSW National Parks and Wildlife Service reports, and unpublished research by the authors, and other members of the School of Environmental and Applied Sciences Griffith University (Table 1). Each exotic species record was classed as either from a natural or a disturbed area; natural locations showed no obvious evidence of human disturbance. Some surveys were specifically undertaken to examine anthropogenic disturbance on vegetation and are more likely to record exotic species. Taxa identified to genus level only were included in these results only when there were no other records of that genus. Species native to NSW but not naturally occurring in Kosciuszko National Park were identified using Duncan (1994). Species names are those currently used in PlantNet (2005). Taxa recorded exclusively in ski resort gardens are listed separately and are not used in comparison with species recorded in other disturbed areas or with species occurring in both natural and disturbed areas. Species recorded in both natural and disturbed areas are considered here to be naturalised species.

Results

Diversity and distribution of exotic taxa (excluding ski resort gardens)

A total of 92 taxa from 23 families were recorded in the 18 vegetation surveys (1986–2004) in the alpine to montane zones of Kosciuszko National Park (1103 records; Tables 3–4). Poaceae had the greatest species richness with 25 taxa, followed by Asteraceae (14), Fabaceae (10), Rosaceae (8), and Caryophyllaceae (4). Over half the families were represented by only one species (Table 2).

Over half the exotic species were forbs (51 taxa); these were also recorded most frequently (71% of records). Graminoids comprised 29 taxa; 27% frequency. Correspondingly, few taxa were shrubs or trees (6 taxa each) (Table 4) possibly an effect of biased sampling as most surveys were conducted in grassland vegetation with few sites in heath or woodland areas (Table 1).

Only three taxa were very common (defined as having an overall frequency ≥ 8% (Table 2). These were the forbs *Acetosella vulgaris* (Sheep Sorrel, 19.7%), *Hypochaeris radicata* (Cat's-ear, Flatweed, 12.6%), and *Trifolium repens* (White Clover, 8%). Six taxa were fairly common; *Agrostis capillaris* (Browntop Bent, 5.3%), *Taraxacum officinale* (Dandelion, 5.3%), *Dactylis glomerata* (Cocksfoot, 4.7%), *Cerastium* spp. (Chickweed, 4.4%), *Anthoxanthum odoratum* (Sweet Vernal Grass, 4.2%) and *Achillea millefolium* (Yarrow, 4%). Together these nine taxa comprised 68% of records. All other species were recorded at low frequency, 2% or less of total records (Table 2).

Disturbed environments

Nearly all exotic taxa (88 out of 92) were associated with anthropogenic disturbance (Table 2). 65 taxa were recorded from road verges. Poaceae, Asteraceae and Fabaceae were the most species rich families in disturbed areas (25, 14 and 10 taxa respectively; Table 2). Correspondingly, forbs and graminoids were the most common lifeform (48 and 29 taxa respectively; Table 4). The most frequent taxa in disturbed areas were *Acetosella vulgaris* (13% of disturbed records e.g. 100 records out of 782 in disturbed sites)

Table 1. Details of 18 general vegetation surveys (1986 to 2004) in montane to alpine zones of Kosciuszko National Park.

Data source	Floristic zone, vegetation type & disturbance type	Details of site, sampling unit & sampling method	Survey year
1. Bear R (2004)	1. Subalpine zone 2. Natural tall alpine herbfield burnt in 2003 bushfires & adjacent unburnt tall alpine herbfield.	Number of sites: 12 **Number of sites with exotics:** 10 **Area of each site:** 6 x 20 m with five 20 m line transects 1.5m apart, sampled **Survey method:** 40 point quadrats every 0.5 m along transects	2004
2. Bear R & Pickering (unpublished data) CM Impacts of fire on road verge vegetation & adjacent natural areas [1]	1. Subalpine zone 2. Disturbed road verge vegetation & adjacent natural grassland.	**Number of sites:** 22 **Length of site:** 3 x 20 m transects at each site **Number of sites with exotics:** 21 **Survey method:** 40 point quadrats per transect (every 50 cm)	2004
3. Campbell M (2004)	1. Alpine zone 2. Natural short alpine herbfield & tall alpine herbfield	**Number of sites:** 15 **Number of sites with exotics:** 1 **Area of each site** 0.3 x 05 m **Survey method** 40 point quadrats for each photoquadrat	2004
4. GLORIA Global (unpublished data) Research Initiative in Alpine Environments (2004 sampling)	1. Alpine zone 2. Natural tall alpine herbfield & heath.	**Number of sites sampled:** 5 **Number of sites with exotics:** 5 **Area of each site:** at least 50 x 50 m **Survey method:** visual estimation	2004
5. Growcock A (2005)	1. Alpine & subalpine zone 2. Natural tall alpine herbfield & subalpine grassland	**Number of sites:** 10 **Area of site:** 2.16 m^2 **Number of sites with exotics:** 1 **Survey method:** visual estimation	2003
6. Hill W & Pickering CM (unpublished data) Effect of drought & fire on alpine & subalpine vegetation in Kosciuszko National Park: severity of initial impact & predictions for recovery.	1. Alpine & subalpine zone 2. Natural tall alpine herbfield, windswept feldmark, heath & subalpine grassland burnt in 2003 bushfires & nearby natural unburnt vegetation.	**Number of sites:** 31 **Number of sites with exotics:** 22 **Size of sites:** 30 x 20 m quadrat. **Survey method:** 200 points sampled by step pointing systematically over site. Rare/uncommon species not detected by step pointing were also recorded and attributed a small default cover value.	2003
7. Johnston F & Johnston SW (2004) [1]	1. Subalpine zone 2. Disturbed road verge vegetation & adjacent natural subalpine grassland vegetation.	**Number of sites:** 18 **Area of site:** 1 x 1 m quadrat **Number of sites with exotics:** 18 **Survey method:** visual estimation	2001
8. Johnston F (2005) [1]	1. Subalpine zone 2. Disturbed road verge vegetation & nearby natural subalpine grassland.	**Number of sites:** 4 **Area of site:** 0 .5 x 0.5 m quadrats **Number of sites with exotics:** 2 **Survey method:** visual estimation	2001

9. Mallen-Cooper J (1990)[1]	1. Alpine, subalpine, montane & tableland zones 2. Disturbed road verge vegetation & nearby natural vegetation	**Number of sites:** 61 **Number of sites with exotics:** 53 **Area of each site:** 20 x 6 m **Survey method:** visual estimation	1986-89
10. Pickering C Appleby M Good R Hill W McDougall K Wimbush D & Woods D (2002)[1]	1. Alpine & subalpine zone 2. Natural tall alpine herbfield, heath, subalpine grassland & subalpine woodland. Disturbed areas in & around ski resorts including ski slopes.	**Number of sites:** 45 **Number of sites with exotics:** 45 **Number of sites in ski resort gardens:** 3 **Area of each site:** at least 50 x 50 m **Survey method:** visual estimation	2002
11. Pickering CM & Hill W (2006)[1]	1. Alpine zone 2. Disturbed vegetation on verges of walking tracks & adjacent natural tall alpine herbfield.	**Number of sites:** 76 **Number of sites with exotics:** 41 **Area of each site:** 1.5 m x 0.5 cm quadrat. **Survey method:** visual estimation	2002
12. Pickering CM Growcock A Hill W Banks J & Field J (unpublished data) Long Plain, Kosciuszko National Park disturbed through prior grazing[1]	1. Montane zone 2. Woodland & grassland disturbed by livestock grazing practices (>40 years previously)	**Number of sites:** 14 (7 woodland & 7 grassland) **Number of sites with exotics:** 14 **Area of each site:** 6 x 1 m quadrat **Survey method:** visual estimation	2003
13. Pickering CM Growcock A Hill W Banks J & Field J (unpublished data) Long Plain Kosciuszko National Park natural areas	1. Montane zone 2. Natural woodland & grassland	**Number of sites:** 14 **Number of sites with exotics:** 14 **Area of each site:** 6 x 1 m quadrat **Survey method:** visual estimation	2003
14. Pickering CM Growcock A Hill W Banks J & Field J (unpublished data) Long Plain Transgrid power lines[1]	1. Montane zone 2. Disturbed heath & grassland under powerlines	**Number of sites:** 7 **Number of sites with exotics:** 7 **Area of each site:** 6 x 1 m quadrat **Survey method:** visual estimation	2003
15. Scherrer P Wimbush D & Wright G (2004)	1. Subalpine zone 2. Natural subalpine grassland and heath	**Number of sites:** 2 **Length of each transect:** 320 m **Number of transects with exotics:** 2 **Survey method:** 3300 point quadrats along each transect	2003-2004
16. Scherrer P (2003) Chapter 4	1. Alpine zone 2. Natural tall alpine herbfield	**Number of sites:** 6 long transects (assessed as 12 sections per transect) **Number of transect sections with exotics:** 5 **Length of each transect section:** ~15.25 m **Survey method:** 99 evenly spaced point quadrats per transect section	2002
17. Scherrer P (2003) Chapter 5	1. Alpine zone 2. Natural tall alpine herbfield	**Number of sites:** 30 photoquadrats **Area of photoquadrat:** 0.7 x 0.9 m **Number of photoquadrats with exotics:** 4 **Survey method:** 130 point quadrats per photoquadrat	2001
18. Scherrer P (2003) Chapter 6	1. Alpine zone 2. Disturbed tall alpine herbfield on rehabilitated walking track 15 years ago & adjacent natural tall alpine herbfield.	**Number of sites:** 42 **Area of site:** 1 x 1 m **Number of sites with exotics:** 18 **Survey method:** visual estimation	2001

[1] Survey examined effect of anthropogenic disturbance on vegetation, therefore more likely to record exotic species.

Table 2. Number of records for each exotic taxon recorded in 18 vegetation surveys (1986 - 2004) in alpine to montane zones of Kosciuszko National Park excluding only taxa recorded in ski resort gardens. (n = 1103 records). Taxa in bold occur in both natural and disturbed areas and hence could be considered naturalized.

Family	Taxon (source)	Lifeform	Natural			Disturbed			Total	Source
			Alpine	Sub alpine	Montane	Alpine	Sub alpine	Montane		
Asteraceae	***Achillea millefolium***	Forb		10	2	1	26	5	44	1,2,7,8,9,10,11
Asteraceae	*Cardus tenuiflorus*	Forb			1				1	9
Asteraceae	*Chondrilla juncea*	Forb						3	3	9
Asteraceae	***Cirsium vulgare***	Forb		2	2		9	11	24	2,9
Asteraceae	***Conyza sumatrensis***	Forb			1			1	2	9
Asteraceae	***Crepis capillaris***	Forb		1	2			13	16	9,10
Asteraceae	***Hypochaeris radicata***	Forb	5	15	30	8	44	37	139	1,2,6,7,9,10, 11,12,13,14,15, 16,17
Asteraceae	***Lactuca serriola***	Forb			2			1	3	9
Asteraceae	***Leontodon taraxacoides***	Forb			1		1		2	10
Asteraceae	***Sonchus asper***	Forb			1			1	2	9
Asteraceae	*Sonchus oleraceus*	Forb					2		2	10
Asteraceae	***Taraxacum officinale* complex**	Forb	2	15	5	9	19	8	58	1,2,6,9, 10,11, 12,15,16
Asteraceae	***Tragopogon dubius***	Forb			2		1	1	4	9,13
Asteraceae	*Tragopogon porrifolius*	Forb					1		1	10
Boraginaceae	*Echium plantagineum*	Forb					4	1	5	7
Boraginaceae	*Echium vulgare*	Forb					3	1	4	9,10
Boraginaceae	***Myosotis discolor***	Forb		1	2		1	3	7	9
Boraginaceae	***Myosotis laxa* subsp. *caespitosa***	Forb			1		1		2	10
Brassicaceae	*Hirschfeldia incana*	Forb					1	1	2	9,10
Brassicaceae	*Erophila verna*	Forb						3	3	9
Caryophyllaceae	*Cerastium* spp.	Forb	1	8	2		17	20	48	2,9,10,11,15
Caryophyllaceae	***Petrorhagia nanteuilii***	Forb			1			2	3	9
Caryophyllaceae	*Sagina apetala*	Forb						1	1	9
Caryophyllaceae	*Spergularia rubra*	Forb				1	5	1	7	9,10
Chenopodiaceae	*Chenopodium album*	Forb						1	1	9
Clusiaceae	*Hypericum calycinum*	Shrub					1		1	10
Fabaceae	*Lotus uliginosus*	Forb			1				1	10
Fabaceae	*Medicago lupulina*	Forb					1		1	9
Fabaceae	*Melilotus alba*	Forb					1		1	9
Fabaceae	*Trifolium ambiguum*	Forb					3	1	4	9,10
Fabaceae	***Trifolium arvense***	Forb			2		2	3	7	9,10
Fabaceae	***Trifolium campestre***	Forb			2			2	4	9
Fabaceae	*Trifolium dubium*	Forb					1	2	3	9,10
Fabaceae	***Trifolium glomeratum***	Forb			2		1	1	4	9,10
Fabaceae	*Trifolium pratense*	Forb					6	1	7	8,9,10
Fabaceae	***Trifolium repens***	Forb		7	4	7	33	37	88	2,6,7,8,9,10, 11,12,14
Gentianaceae	***Centaurium erythraea***	Forb			1			3	4	9
Geraniaceae	*Erodium cicutarium*	Forb						3	3	9
Juncaceae	*Juncus acutiflorus*	Graminoid						1	1	9
Juncaceae	*Juncus articulatus*	Graminoid					1		1	9
Juncaceae	*Juncus bufonius*	Graminoid					1		1	10
Juncaceae	***Juncus effusus***	Graminoid			1		4		5	10
Lamiaceae	*Prunella vulgaris*	Forb						1	1	9
Lamiaceae	*Salvia verbenaca*	Forb						1	1	9
Malvaceae	*Malva parviflora*	Shrub					1		1	10

			Natural			Disturbed				
Family	**Taxon (source)**	**Lifeform**	**Alpine**	**Sub alpine**	**Montane**	**Alpine**	**Sub alpine**	**Montane**	**Total**	**Source**
Onagraceae	***Epilobium ciliatum***	Forb			2		5		7	10
Pinaceae	*Pinus mugo*	Tree		1					1	16
Plantaginaceae	***Plantago lanceolata***	Forb			1		11	5	17	2,9,10,13,14
Poaceae	***Agrostis capillaris***	Graminoid	1	5		2	29	21	58	1,2,9,10,11,15
Poaceae	*Agrostis stolonifera*	Graminoid					1		1	10
Poaceae	***Aira caryophyllea***	Graminoid		1	2		2	4	9	9,10,15
Poaceae	***Anthoxanthum odoratum***	Graminoid		16	2		23	5	46	1,2,7,8,9,10,15
Poaceae	*Bromus cartharticus*	Graminoid					1		1	10
Poaceae	*Bromus diandrus*	Graminoid					1		1	10
Poaceae	***Bromus hordeaceus***	Graminoid			1		3	3	7	9
Poaceae	*Bromus racemosus*	Graminoid					1		1	10
Poaceae	***Bromus sterilis***	Graminoid		1			1		2	9
Poaceae	*Bromus tectorum*	Graminoid					2	2	4	9
Poaceae	***Dactylis glomerata***	Graminoid		3	4		24	21	52	2,9,10,12,13
Poaceae	*Festuca arundinacea*	Graminoid					1		1	10
Poaceae	***Festuca rubra***	Graminoid	1	3	1	1	15	2	23	2,9,10,11
Poaceae	***Holcus lanatus***	Graminoid		1	2		11	2	16	2,9,10
Poaceae	*Hordeum leporinum*	Graminoid						1	1	10
Poaceae	*Hordeum vulgare*	Graminoid					1		1	10
Poaceae	***Lolium perenne***	Graminoid			1		2	2	5	9
Poaceae	*Panicum gilvum*	Graminoid					1	1	2	9
Poaceae	*Paspalum dilatatum*	Graminoid						1	1	9
Poaceae	***Phleum pratense***	Graminoid		2	2		14	1	19	2,9,10
Poaceae	***Poa annua***	Graminoid			2	1	10	2	15	9,10
Poaceae	*Poa bulbosa*	Graminoid						1	1	9
Poaceae	***Poa pratensis***	Graminoid		3	1	1	13	1	19	2,9,10,11
Poaceae	***Vulpia bromoides***	Graminoid			1			1	2	9
Poaceae	***Vulpia myuros***	Graminoid			1			3	4	9
Polygonaceae	***Acetosella vulgaris***	Forb	52	41	25	26	39	34	217	1,2,4,5,6,7,8, 9,10,11,12,13, 14,15,16,17,18
Polygonaceae	*Polygonum* spp.	Forb					4	3	7	9
Polygonaceae	*Rumex crispus*	Forb					2		2	9,10
Primulaceae	*Anagallis arvensis*	Forb						1	1	9
Rosaceae	***Aphanes arvensis***	Forb			1			2	3	9
Rosaceae	***Malus x domestica***	Tree		1	1		2	1	5	9,10
Rosaceae	*Potentilla recta*	Shrub					1		1	10
Rosaceae	*Prunus armeniaca*	Tree					1		1	10
Rosaceae	*Prunus lusitanica*	Tree					1		1	10
Rosaceae	*Prunus persica*	Tree					1		1	10
Rosaceae	***Rosa rubiginosa***	Shrub			1		1		2	9,10
Rosaceae	*Rubus fruticosus* spp.agg.	Shrub						1	1	9
Salicaceae	***Salix* sp.**	Tree			1		1		2	10
Scrophulariaceae	*Linaria arvensis*	Forb			1				1	9
Scrophulariaceae	*Mimulus moschatus*	Shrub					1		1	10
Scrophulariaceae	***Verbascum thapsus***	Forb			1		1	3	5	9,10
Scrophulariaceae	***Verbascum virgatum***	Forb		1	1		3	3	8	9,10
Scrophulariaceae	***Veronica arvensis***	Forb			1			2	3	9
Violaceae	*Viola arvensis*	Forb					1		1	9
Total records			**62**	**138**	**124**	**57**	**422**	**300**	**1103**	
Number of species			**6**	**21**	**45**	**10**	**63**	**60**	**92**	

1 Disturbed areas were defined as those with obvious evidence of anthropogenic disturbance.

2 Taxa/taxon identified to genus level only.

Sources (see Table 1 and References for details)

Hypochaeris radicata (11%, 89 records), *Trifolium repens* (10%, 77 records) *Agrostis capillaris* (7%, 52 records) and *Dactylis glomerata* (6%, 45 records).

The gardens of ski resorts with 81 taxa were a major potential source of exotic species, 62 of which were only recorded from the gardens. Some of these species are naturalised outside our Kosciuszko National Park survey areas and others may naturalise in the future (See Appendix).

Natural environments

Fewer exotic taxa were recorded in natural areas (48 taxa, Table 2). Of these, 44 taxa were also found in disturbed areas (Table 2). Poaceae, Asteraceae and Fabaceae were again the most species-rich families (14, 11, and 5 taxa respectively; Table 2). Correspondingly, forbs and graminoids were the most common lifeform (29 and 15 taxa respectively; Table 4). The small ubiquitous herb *Acetosella vulgaris* accounted for 36% (117) of all records in natural areas (322 records; Table 2). The only other common species in natural areas were *Hypochaeris radicata* (16%, 50 records) *Taraxacum officinale* (6%, 21 records) and *Anthoxanthum odoratum* (6%, 18 records, Table 2). Four exotic taxa were recorded exclusively in natural areas although with very low frequency *Carduus tenuiflorus* (Winged Thistle), *Linaria arvensis* (Corn Toadflax), *Lotus uliginosus* (Greater Birdsfoot Trefoil), and *Pinus mugo* (only one record each).

Floristic zone

Of the 11 exotics in the alpine zone, *Acetosella vulgaris* was by far the most frequent (66%, 78 of the total of 119 alpine records; Table 2). Other frequent species were *Taraxacum officinale* (10%, 11 records in alpine) and *Hypochaeris radicata* (11%, 13 records). *Trifolium repens* was relatively common (6%, 7 records) but was only found on the verge of walking tracks. Six of the eleven taxa (*Acetosella vulgaris, Achillea millefolium, Agrostis capillaris, Epilobium ciliatum, Hypochaeris radicata, Taraxacum officinale*) were found in natural areas (Table 2).

The subalpine and montane zones both had numerous exotic taxa. Of the 66 exotic taxa in the subalpine zone, only 36% were recorded in natural areas, whereas, 69% of the 69 exotic taxa in the montane zone taxa were recorded in natural areas (Table 2). *Acetosella vulgaris* was again the most common species in the subalpine zone and was equally frequent in natural and disturbed areas (14%, 80 of the 561 records in the subalpine). *Hypochaeris radicata* was also common in the subalpine zone (11%, 59 subalpine records) but was more frequent in disturbed areas (8%, 44 records) than in natural areas. *Hypochaeris radicata* (14%, 59 records) and *Acetosella vulgaris* (16%, 67 records) were the most frequent exotic taxa in the montane zone and equally common in natural and disturbed areas. The frequency of most taxa in both montane and subalpine zones was very low, with around 65% of taxa having < 1% of records (Table 2).

Table 3. Number (%) of exotic plant taxa from 18 vegetation surveys (1986 - 2004) in alpine to montane zones of Kosciuszko National Park, excluding taxa only recorded in ski resort gardens. n = 1103 records of exotic taxa.

[1]Disturbed areas were defined as those with obvious evidence of anthropogenic disturbance.

	Alpine	Subalpine	Montane	Total
Natural vegetation	6 (5%)	21 (34%)	45 (48%)	48 (51%)
Disturbed vegetation[1]	10 (11%)	64 (70%)	60 (64%)	88 (95%)
Total	11 (12%)	66 (72%)	69 (74%)	92

Table 4. Number of exotic taxa in each lifeform recorded in 18 vegetation surveys (1986 to 2004) in alpine to montane zones of Kosciuszko National Park, excluding taxa only recorded in ski resort gardens, n = 1103 records of exotic taxa.

[1]Disturbed areas were defined as those with obvious evidence of anthropogenic disturbance.

		Natural			Disturbed		Total	
Lifeform	Alpine	Subalpine	Montane	Alpine	Subalpine	Montane	Number	(%)
Forb	4	10	29	6	31	39	51	71
Graminoid	2	9	13	4	23	19	29	27
Shrub			1		5	1	6	0.6
Tree		2	2		5	1	6	1
Total	6	21	45	10	64	60	92	100

Crepis capillaris is a species that may need to be monitored as it is relatively common along road verges in the montane zone and has been recorded in montane woodland, but so far appears to be infrequent in the subalpine zone.

The most common taxa

Nine taxa are common in all zones in both natural and disturbed areas and together accounted for 68% of all records (Table 5). The most common species were *Acetosella vulgaris* and *Hypochaeris radicata* which together comprise 32% of all records). Some of the taxa were formerly used in vegetation rehabilitation programs (*Dactylis glomerata* and *Agrostis capillaris*); however, other rehabilitation species (*Lolium perenne, Holcus lanatus, Festuca rubra, Phleum pratense*) while present in subalpine end montane zones, are uncommon. All nine common weeds are perennial forbs or graminoids native to Europe and are naturalized in Australia (Table 5). Most of them can reproduce vegetatively, by rhizomes or stolons, and can be found in mountains in other regions of the world. They are well established in the Australian Alps and are commonly found in other recent vegetation surveys, particularly along roads (McDougall 2001; Godfree et al. 2004). Several were recorded in the earliest plant surveys in the Australian Alps, and all date back to the grazing period (Johnston & Pickering 2001).

Discussion

Increased diversity and abundance of exotics

European landuse in Kosciuszko National Park has resulted in the introduction and spread of exotic taxa over the last 150 years. On Mount Kosciuszko in the 1890's Joseph Maiden (1898, 1899) recorded four exotic taxa in the montane zone, and three in the subalpine zone, but none in the alpine zone. Costin's (1954) extensive survey of the Monaro region, done in the mid-1950s following 100 years of livestock grazing, recorded 67 exotic species in the montane zone, 44 in the subalpine zone, and six in the alpine zone.

Using data from 18 general surveys undertaken between 1986 and 2004 we have recorded 69 taxa in the montane, 66 taxa in the subalpine and 11 taxa in the alpine zones, with a total of 92 exotic taxa overall. An additional 62 exotic taxa were

Table 5. Characteristics of the nine most common taxa recorded in 18 vegetation surveys in Kosciuszko National Park (1986 - 2004) excluding taxa only recorded in ski resort gardens, n = 1103 records. (sources for characteristics are Harden 1993, Lamp and Collet 1996, Blood 2001, PlantNet 2005). Recorded in 1899 = Maiden (1899), Recorded in 1954 = Costin (1954).

Species (family)	Lifeform	Life history strategy	Origin (native to)	Naturalized/invasive in Australia	Recorded in
Acetosella vulgaris (Polygonaceae)	Forb	Perennial	Europe, North Africa, Temperate Asia	Yes	1899
Achillea millefolium (Asteraceae)	Forb	Perennial	Europe, Temperate Asia, North America	Yes	1954
Agrostis capillaris (Poaceae)	Graminoid	Perennial	Europe, North Africa, Temperate Asia	Yes	1954
Anthoxanthum odoratum Poaceae)	Graminoid	Perennial	Europe, Temperate Asia, North Africa	Yes	1954
Cerastium spp. (Caryophyllaceae)	Forb	Perennial	Europe, North Africa, Temperate Asia	Yes	1954
Dactylis glomerata Poaceae)	Graminoid	Perennial	Europe, North Africa, Temperate Asia	Yes	1954
Hypochaeris radicata (Asteraceae)	Forb	Perennial	Europe, North Africa, Temperate Asia	Yes	1899
Taraxacum officinale (Asteraceae)	Forb	Perennial	Europe, Asia	Yes	1899
Trifolium repens (Fabaceae)	Forb	Perennial	Europe, North Africa, Temperate Asia	Yes	1954

recorded in the subalpine zone from ski resort gardens only, although 12 of these are reported to be naturalised elsewhere (Johnston & Pickering 2001).

Most recently McDougall et al. (2005) have recorded 128 invasive species, based on 1400 floristic quadrats in just the treeless vegetation in the Australian Alps above 1200 m.

Rehabilitation species and common forbs

Some exotics recorded in this study were intentionally introduced as part of rehabilitation projects. Grasses such as *Agrostis capillaris*, *Festuca rubra*, *Lolium perenne*, *Dactylis glomerata* and *Phleum pratense* were used in the 1950s in rehabilitation work carried out to counteract erosion caused by livestock grazing in the higher altitude areas of Kosciuszko National Park (Costin 1954, Mallen 1984). These species were inexpensive, available in commercial quantities and known to rapidly establish protective ground cover (Mallen 1984). It was expected that native species would replace exotic species when soil conditions returned to 'normal', but recent studies suggest that this may not be occurring as quickly as once thought, especially in areas experiencing continued disturbance (McDougall 2001, Scherrer 2003). In some high altitude sites, rehabilitated sites have started to re-erode (Johnston et al. 2002). These species are still present in disturbed sites along road verges in the subalpine zone, with *Agrostis capillaris* and *Festuca rubra* also associated with tracks in the alpine zone. They have been recorded from natural areas in the montane zone. *Agrostis capillaris* is of concern as it is considered to be particularly persistent, even in the absence of continued disturbance (McDougall 2001).

Future

This study, like those in the past, highlights the increasing abundance and diversity of exotics in the Australian Alps, and the need for effective management. The recent extensive bushfires in Kosciusko National Park in January-February 2003 burnt over 486 000 ha, including more than 70% of the subalpine zone (NPWS 2004, ISC 2004). Immediately after the fire there was a dramatic loss of native vegetative cover, including areas near roads and tracks (Bear 2004, Scherrer et al. 2004). However few road verges, or areas around ski resorts and other infrastructure were burnt, leaving exotic taxa there unaffected and able to disperse seed into recently burnt areas. As a result, there is the potential for the spread of exotics from anthropogenically-disturbed sites into areas previously covered by intact native vegetation (Johnston & Johnston 2003, Costin et al. 2004).

Climatic change is also likely to increase the spread of exotics (Scherrer & Pickering 2001; Pickering & Armstrong 2003, Pickering et al. 2004). An increase in temperature between +0.6, and +2.9°C, as predicted for the Australian Alps, would result in between 38–96% decrease in the area receiving at least 60 days of snow cover by 2050 (Henessey et al. 2003). As the distribution and abundance of some exotic taxa is thought to be limited by current climatic conditions (Mallen-Cooper 1990, Pickering & Armstrong 2003, Pickering et al. 2004, McDougall et al. 2005) it is likely that there could be even greater invasion and distribution of exotic taxa as conditions change (Pickering et al. 2004, McDougall et al. 2005). For example, in a study of treeless vegetation in the Australian Alps, approximately 22 invasive species were recorded above 1800m, and 41 invasive species between 1600m and 1800m. If, as predicted, climatic conditions above 1800m became more similar to those currently at lower elevations, it is likely that there will be a dramatic increase in the number of exotic species including in natural treeless vegetation in the Park (McDougall et al. 2005). This highlights the importance of managing the current threat from exotics before they have an even greater impact.

References

Adair, R.J. (1995) The threat of environmental weeds to biodiversity in Australia: a search for solutions. In *Conserving biodiversity: threats and solutions* (eds. RA Bradstock, TD Auld, DA Keith, RT Kingsford, D Lunney and DP Sivertsen) (Surrey Beatty and Sons: Sydney) pp. 184–201.

Bear, R. (2004) *Comparing unburnt and burnt subalpine grasslands one year after wildfire* Honours Thesis, School of Environmental and Applied Sciences, Griffith University, Gold Coast.

Blood, K. (2001) *Environmental weeds: a field guide for SE Australia.* (CH Jerram & Associates Science Publishers: Mt Waverley).

Blossey, B. (1999) Before, during and after: the need for long-term monitoring in invasive plant species management. *Biological Invasions* 1: 301–311.

Campbell, M. (2004) Vegetation associated with the latest lying snowbanks in Australia Honours thesis, School of Environmental & Applied Sciences, Griffith University, Gold Coast.

Costin, A.B. (1954) *A study of the ecosystems of the Monaro Region of New South Wales with special reference to soil erosion* (Soil Conservation Service of NSW: Sydney).

Costin, A.B., Gray, M., Totterdell, C. & Wimbush, D. (2000) *Kosciuszko alpine flora* (CSIRO Publishing: Collingwood, Victoria).

Costin, A.B., Wimbush, D. & Kirkpatrick, J.B. (2004) Flora values In *An assessment of the values of Kosciuszko National Park: a Report by the Independent Scientific Committee.* (NSW National Parks and Wildlife Service: Sydney) pp. 55–72.

Csurhes, S. & Edwards, R. (1998) *Potential environmental weeds in Australia* (Environment Australia: Canberra).

Duncan, A. (1994) *Guide to the native ferns, conifers and flowering plants in Kosciuszko National Park.* (NSW National Parks and Wildlife Service and Royal Botanic Gardens: Sydney).

Godfree, R., Lepschi, B. & Mallinson, D. (2004) Ecological filtering of exotic plants in an Australian sub-alpine environment. *Journal of Vegetation Sciences* 15: 227–236.

Good, R.B. (1992a) The Australian Alps. In *The Australian Alps* Volume 80. (eds P. Grenier and R.B. Good) (Institute de Géographie Alpine: Grenoble) pp. 39–63.

Good, R.B. (1992b) *Kosciuszko heritage* (National Parks and Wildlife Service of NSW: Sydney).

Green, K. & Osborne, W. (1994) *Wildlife of the Australian snow-country* (Reed Books: Sydney).

Growcock, A. (2005) Trampling impacts in Kosciuszko National Park, Australia PhD thesis, School of Environmental and Applied Sciences, Griffith University, Gold Coast.

Happold, D.C.D. (1998) The subalpine climate at Smiggin Holes, Kosciuszko National Park, Australia, and its influence on the biology of small mammals. *Arctic, Antarctic and Alpine Research* 30: 241–251.

Harden, G.J. (1990) *Flora of New South Wales* Volume 1. (NSW University Press: Sydney).

Helms, R. (1893) Report on the grazing leases of the Mount Kosciusko plateau. *Agricultural Gazette of New South Wales* 530–531.

Hennessy, K., Whetton, P., Smith, I., Bathols, J., Hatchinson, M. & Sharples, J. (2003) *The impact of climate change on snow conditions in mainland Australia*. (Commonwealth Scientific Industrial and Research Organisation, Atmospheric Research: Melbourne).

Hill, W. & Pickering, C.M. (2006) Vegetation associated with different walking track types in the Kosciuszko alpine area, Australia. *Journal of Environmental Management* 78: 23–34).

ISC (Independent Scientific Committee)(2004) *An Assessment of the Values of Kosciuszko National Park* (NSW National Parks and Wildlife Service: Sydney).

Johnston, S., Greene, R., Banks, J. & Good, R. (2002) Function and sustainability of Australian ecosystems: studies in the tall alpine herbfield community, Kosciuszko National Park, NSW, Australia In *Proceedings of Ecological and Earth Sciences Conference* (eds. L. Taylor, K. Martin D. Hik & A. Ryall) (The Banff Centre: Banff). pp. 226–234.

Johnston, F.M. & Johnston, S.W. (2003) Weeds set to flourish following fires. *Victorian Naturalist* 120: 194–197.

Johnston, F. & Johnston, S.W. (2004). Impacts of road disturbance on soil properties & on exotic plant occurrence in subalpine areas of the Australian Alps *Arctic, Antarctic & Alpine Research* 36: 201–207.

Johnston, F. (2005) Exotic plants in the Australian Alps including a case study of the ecology of *Achillea millefolium* in Kosciuszko National Park PhD thesis, School of Environmental and Applied Sciences Griffith University, Gold Coast.

Johnston, F.M. & Pickering, C,M. (2001) Exotic plants in the Australian Alps. *Mountain Research and Development* 21: 284–291.

Körner, C. (1999) *Alpine plant life: functional plant ecology of high mountain ecosystems* (Springer-Verlag: Berlin).

Lamp, C. & Collet, F. (1999) *Field guide to weeds in Australia* (Inkata Press: Melbourne).

Lamp, C.A., Forbes, S.J. and Cade, J.W. (2001) *Grasses of Temperate Australia. A field Guide* Revised Edition (CH Jerram: Melbourne)

Maiden, J.H. (1898) A contribution towards a flora of Mount Kosciusko. *Agricultural Gazette of New South Wales* 9: 720–740.

Maiden, J.H. (1899) A second contribution towards a flora of Mount Kosciusko. *Agricultural Gazette of New South Wales* 10: 1001–1042.

Mallen, J. (1984) Revegetation and rehabilitation, Kosciuszko National Park, New South Wales: a literature review (NSW National Parks and Wildlife Service: Jindabyne).

Mallen-Cooper, J. (1990) Exotic plants in the high altitude environments of Kosciuszko National Park, South-eastern Australia PhD Thesis. Department of Biogeography and Geomorphology, Research School of Pacific Studies, Australian National University, Canberra.

McDougall, K.L. (2001) Colonization by alpine native plants of a stabilized road verge on the Bogong High Plains, Victoria. *Ecological Management and Restoration* 2: 47–52.

McDougall, K.L. & Appleby, M.L. (2000) Plant invasions in the high mountains of north-eastern Victoria. *Victorian Naturalist* 117: 52–59.

McDougall, K.L., Morgan, J.W., Walsh, N.G. & Williams, R.J. (2005) Plant invasions in treeless vegetation of the Australian Alps. *Perspectives in Plant Ecology, evolution and Systematics* 7: 159–171.

NPWS (NSW National Parks and Wildlife Service) (2004) Kosciuszko National Park 2004: draft plan of management (NSW National Parks and Wildlife Service: Queanbeyan).

Pickering, C.M. & Armstrong, T. (2003) Potential impact of climate change on plant communities in the Kosciuszko alpine zone. *Victorian Naturalist* 120: 263–272.

Pickering, C.M., Appleby, M., Good, R., Hill, W., McDougall, K.L., Wimbush, D., & Woods, D. (2002) Plant diversity in subalpine and alpine vegetation recorded in the Kosciuszko 2002 Biodiversity Blitz In: *Biodiversity in the Mountains* (ed K. Green) (Australian Institute of Alpine Studies: Jindabyne) pp. 27–46.

Pickering, C.M., Good, R. & Green, K. (2004) *The ecological impacts of global warming: potential effects of global warming on the biota of the Australian Alps* (Australian Greenhouse Office: Canberra).

Pickering, C.M., Kirkwood, A. & Arthur, J.M. (2003) Habitat and sex specific differences in the dioecious weed *Acetosella vulgaris* (Polygonaceae). *Austral Ecology* 28: 396–403.

PlantNet (2005) National Herbarium of New South Wales (1999–2005) New South Wales flora online National Herbarium of New South Wales, Royal Botanic Gardens & Domain Trust, Sydney Australia (http://plantnet.rbgsyd.nsw.gov.au/) Visited in November 2005.

Prieur-Richard, A.H. & Lavorel, S. (2000) Invasions: the perspective of diverse plant communities. *Austral Ecology* 25: 1–7.

Scherrer, P. (2003) Monitoring vegetation change in the Kosciuszko alpine zone, Australia PhD Thesis. School of Environmental and Applied Sciences, Griffith University, Gold Coast.

Scherrer, P. & Pickering, C.M. (2001) Effects of grazing, tourism and climate change on the alpine vegetation of Kosciuszko National Park *Victorian Naturalist* 118: 93–99.

Scherrer, P., Wimbush, D. & Wright, G. (2004) *The assessment of pre and post 2003 wildfire data collected from subalpine transects in Kosciuszko National Park* (Department of Environment and Conservation, National Parks and Wildlife Division: Jindabyne).

Williams, J.A. & West, C.J. (2000) Environmental weeds in Australia and New Zealand: issues and approaches to management. *Austral Ecology* 25: 425–444.

Wimbush, D. & Costin, A.B. (1979) Trends in vegetation at Kosciuszko. I Grazing trials in the subalpine zone, 1957–1971. *Australian Journal of Botany* 27: 741–787.

Worboys, G. & Pickering, C.M. (2002) *Managing the Kosciuszko alpine area: conservation milestones and future challenges. Mountain Tourism Research Report Series: No. 3* (Cooperative Research Centre for Sustainable Tourism, Griffith University: Gold Coast).

Manuscript accepted 14 March 2006

Appendix. Exotic taxa found in ski resort gardens (Pickering et al. 2002) and not recorded in Table 2.

Family	Taxon	Lifeform
Aceraceae	*Acer negundo*	Tree
Aceraceae	*Acer pseudoplatanus*	Tree
Apocynaceae	*Vinca major*[1]	Forb
Apocynaceae	*Vinca minor*	Forb
Aquifoliaceae	*Ilex aquifolium*	Tree
Aquifoliaceae	*Ilex cornuta*	Shrub
Araliaceae	*Hedera helix*	Shrub
Asteraceae	*Anthemis tinctoria*	Forb
Asteraceae	*Artemisia absinthium*	Shrub
Asteraceae	*Aster alpinus*	Forb
Asteraceae	*Leucanthemum* x *superbum*	Forb
Baueraceae	*Bauera rubioides*	Forb
Betulaceae	*Alnus incana*	Tree
Betulaceae	*Betula pendula*	Tree
Boraginaceae	*Myosotis sylvatica*	Forb
Brassicaceae	*Aurinia saxatilis*	Forb
Caprifoliaceae	*Lonicera japonica*	Shrub
Caprifoliaceae	*Lonicera nitida*	Shrub
Caryophyllaceae	*Dianthus barbatus*	Forb
Caryophyllaceae	*Dianthus subacaulis*	Forb
Commelinaceae	*Tradescantia* Andersoniana Group	Forb
Crassulaceae	*Echeveria secunda*	Forb
Crassulaceae	*Sedum* spp.[2]	Forb or shrub
Crassulaceae	*Sempervivum montanum*	Forb
Dipsacaceae	*Scabiosa columbaria*	Forb
Ericaceae	*Erica* sp.[2]	Forb
Ericaceae	*Rhododendron* sp.[2]	Tree
Fabaceae	*Cytisus scoparius*[1]	Shrub
Fabaceae	*Lotus corniculatus*	Shrub
Fabaceae	*Lupinus polyphyllus*[1]	Forb
Fabaceae	*Wisteria* sp.[2]	Shrub
Iridaceae	*Iris* spp.[2]	Forb
Juncaceae	*Juncus tenuis*	Graminoid
Lamiaceae	*Lavandula angustifolia*	Forb
Lamiaceae	*Origanum vulgare*	Forb
Lamiaceae	*Stachys byzantina*	Forb
Lamiaceae	*Thymus* sp.[2]	Forb
Lamiaceae	*Westringia fruticosa*	Shrub
Liliaceae	*Agapanthus* sp.[1]	Forb
Liliaceae	*Muscari armeniacum*	Shrub
Linaceae	*Linum perenne*	Forb
Myrtaceae	*Eucalyptus cordata*	Tree
Oleaceae	*Syringa vulgaris*	Shrub
Onagraceae	*Oenothera rosea*	Forb
Poaceae	*Avena barbata*	Graminoid
Proteaceae	*Grevillea juniperina*	Shrub
Proteaceae	*Grevillea rosmarinifolia*	Shrub
Rosaceae	*Duchesnea indica*	Forb
Rosaceae	*Fragaria* sp.[2]	Forb
Rosaceae	*Photinia glabra* 'Rubens'	Shrub
Rosaceae	*Prunus avium*	Tree
Rosaceae	*Prunus cerasifera*	Tree
Rosaceae	*Pyracantha crenulata*	Tree
Rosaceae	*Rosa multiflora*	Shrub
Rosaceae	*Spiraea thunbergii*	Shrub
Salicaceae	*Populus alba*	Tree
Salicaceae	*Populus nigra*	Tree
Salicaceae	*Salix cinerea*[1]	Tree
Scrophulariaceae	*Misopates orontium*	Forb
Tiliaceae	*Tilia cordata*	Tree
Ulmaceae	*Ulmus parvifolia*	Tree
Ulmaceae	*Ulmus procera*'Louis van Houtte'	Tree

Total number of families	39
Total number of taxa	62
Total number of forb taxa	28
Total number of shrub taxa	16
Total number of tree taxa	16
Total number of graminoid taxa	2

[1] Taxon has been recorded in Kosciuszko National Park previously but not recorded in 18 surveys (Table 3).

[2] Taxon/taxa identified to genus level only.

Primary vegetation development on the sand spit of Shallow Inlet, Wilsons Promontory, southern Victoria

Petrus C. Heyligers

CSIRO Sustainable Ecosystems, Queensland Biosciences Precinct, 306 Carmody Road, St. Lucia, Q 4067, AUSTRALIA.
petrus.heyligers@csiro.au

Abstract: The sand spit that separates Shallow Inlet from Waratah Bay (38°52′ S, 146°13′ E), near Wilsons Promontory in southern Victoria, has developed since the previous spit was washed out in 1901. Initially without vegetation, the spit was colonised in the 1960s by the exotic grasses **Thinopyrum junceiforme* and to a lesser extent **Ammophila arenaria*. These species are native to the coast of western Europe, where they fulfil a key role in dune establishment. Being able to grow through sand accumulating among the culms, these grasses formed mounds where seeds or rhizome fragments were washed up during king tides. Where somewhat sheltered from the strongest impact of the westerlies, mounds gradually coalesced and formed short ridges at the landward side of the spit, and 'dune fields' towards its distal end. Circumstances favourable for dune field formation were enhanced by episodic processes in spit growth due to channel shifting in the tidal delta and the gradual lengthening of the main outlet channel.

Austrofestuca littoralis and *Spinifex sericeus* joined the two foreign grasses in their pioneering role. The herbaceous *Actites megalocarpa* and the shrub *Ozothamnus turbinatus* established in the lee of the grasses, but conditions on mounds, dune crests and windward slopes are too severe for other species. Only at more sheltered sites is further development of vegetation possible. In the lee of the dune fields it has progressed into an open shrubland, initially of *Ozothamnus turbinatus*, *Olearia axillaris* and *Olearia glutinosa*, later enriched by *Acacia longifolia* var. *sophorae*, *Leptospermum laevigatum* and *Leucopogon parviflorus*. Wind-dispersed taxa form the dominant component of the vegetation, but several animal-dispersed species became established as well. The complement of woody species begins to resemble that of the dune scrub found elsewhere along this part of the Victorian coast, but several wind-dispersed species, notably *Banksia integrifolia*, are still lacking and it would appear that dispersal is still a limiting factor in vegetation development. It is pointed out that dune development on the sand spit was initiated by exotic grasses and that without their presence, it is doubtful whether any vegetation would have established there.

Many photos support the text- *the narrative will say what words can say but words can never say it all* (Love 1999).

***Cunninghamia* (2006) 9(4): 571–596**

Introduction

Shallow Inlet forms an embayment in the northeastern corner of Waratah Bay from which it is separated by a sand spit (38°52′ S, 146°13′ E; Fig. 1). It is one of the South Gippsland Marine and Coastal Parks and is contiguous with Wilsons Promontory National Park. In the terrestrial zoning for recreational activities in the Shallow Inlet Marine and Coastal Park the sand spit is classified as a Reference Zone, and no human activity of any kind, including passive recreation, is allowed there (Anon 1986, 1990).

In the late 1970s I began investigating the sand-collecting abilities of indigenous and introduced coastal plant species (Heyligers 1985) and used the spit as one of the study sites. As it was still accreting, it provided an opportunity to observe sand-interception by individual plants as well as dune formation and vegetation development. I expected that succession would demonstrate what is usually inferred from toposequences: a steady progression from pioneering grasses through a shrubby phase to taller woody vegetation (e.g. Barson & Calder 1976). However, developments on the spit did not follow such an orderly pattern and in this paper I report what actually happened.

Geomorphological setting

The largely sandy shore of Waratah Bay extends from Cape Liptrap to the mouth of the Darby River (Fig. 1a). Shallow bottom sediments are gradually transported inshore by the south-westerly swell generated in the Southern Ocean and moved to the northeastern side of the bay by longshore currents. The gently sloping beach, more than 200 m wide at low tide, and a series of offshore bars as well as the formation of additional foredune ridges, are the result of this depositional environment (Bird 1977, 1993).

Shallow Inlet has only a small catchment; hence the water regime is predominantly tidal. During ebb, large areas fall dry, leaving a meandering channel that shoals into a tidal delta at the entrance. Tidal amplitudes in Waratah Bay are about 1.9 m, with only a small difference between neap and spring tides. Strong to gale-force winds may increase tidal height by 0.5 m, sufficient to inundate low-lying areas of the spit. On occasions, in the lowest sections, overwash reaches the channel shore. Fresh to strong westerly and southwesterly winds are predominant; those from the northwest and northeast are less frequent and usually light to moderate. Rainfall is about 850 mm/yr; monthly totals vary from about 40 mm during the summer months to more than double that amount during late autumn and winter (Smith 1969).

The entrance to Shallow Inlet has a chequered history (Smith 1969, Cecil 1983, Bird 1993). A spit was present in the middle of the nineteenth century, but broke through in 1901 and the entrance shifted towards Sandy Point (Fig. 2). The old entrance sanded up, thus joining what was left of the spit with the opposite shore. However, sand conveyed by longshore currents began to block the channels in the northwest part of the delta, forcing the main channel to shift to the southeast. Thus, another spit began to form, a process that is still continuing. Smith (1969) was the first to broadly analyse it, while Cecil (1983) provided a detailed explanation of the channel dynamics of the ebb tidal delta. They concluded that the erosional and depositional effects of the tidal currents in combination with the easterly longshore drift lead to a gradual extension of the spit. While both authors concentrated on erosional aspects, less attention was paid to accretional ones. The latter, however, are critically important for understanding later dune formation.

The role of plants in dune formation

The sand-collecting capacity of plants, and consequent mound building have been reported from both coastal and desert environments (e.g. Hesp 1981, Rundle *et al.* 1991, Hesp & McLachlan 2000). The result of the interactions between wind, sand and plants depends on the growth form of the colonising species (Hesp 1982, Heyligers 1985, Danin

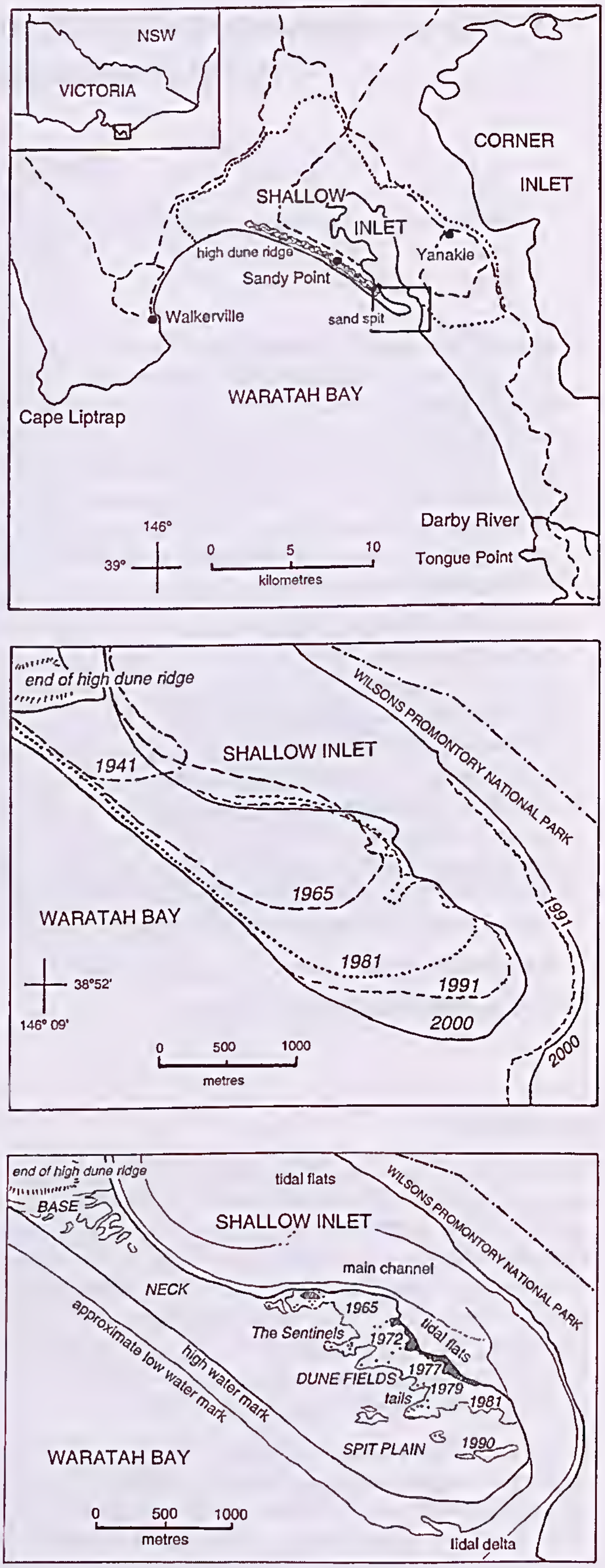


Fig. 1. Location, history and features of the sand spit at the mouth of Shallow Inlet. (a) Position along the northeast shore of Waratah Bay. Roads are indicated with broken lines, the watershed boundary of Shallow Inlet is outlined with a stipple line. (b) Growth of the sand spit since 1941; erosion of the opposite shore has only been mapped for 1991 and 2000; earlier shore outlines would overlap the position of the spit (see Figs. 2 and 4). (c) Features of the spit mapped from the 2001 airphoto. Names used to facilitate description are in italics, as are the dates approximately indicating when the first mounds appeared which lead to the formation of that section of the dune fields. The dots represent some of the more prominent mounds. The hatched area along the inlet shore indicates the *Thinopyrum* flats, that at the west end of the 1965 section the densely vegetated hollow.

1996). Sand-bearing winds leave a ridge in the lee of tussocks and bushy plants (Fig. 3). Height and width of the ridge are mainly determined by plant shape, but length depends on the strength of the airflow around the sides: stronger winds and variable wind directions leave shorter ridges. Turbulence created behind the top of a plant causes the highest point of the ridge often to be located behind the plant, rather than in it. Low, horizontally spreading plants enlarge surface drag rather than split the airflow vertically. The resultant turbulence causes sand to precipitate in the small wake areas amidst leafy branches and runners, resulting in the formation of lower, wider mounds.

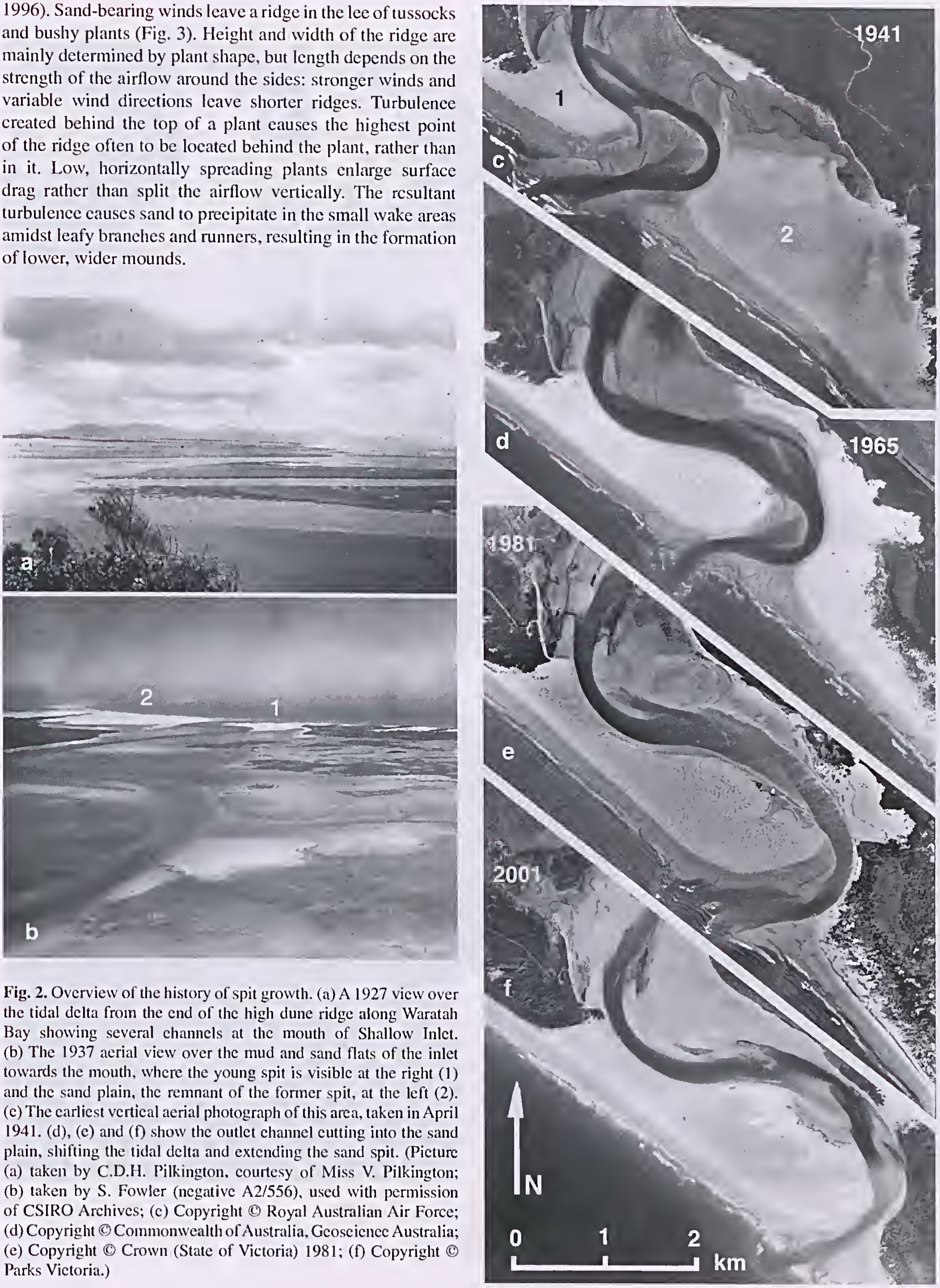


Fig. 2. Overview of the history of spit growth. (a) A 1927 view over the tidal delta from the end of the high dune ridge along Waratah Bay showing several channels at the mouth of Shallow Inlet. (b) The 1937 aerial view over the mud and sand flats of the inlet towards the mouth, where the young spit is visible at the right (1) and the sand plain, the remnant of the former spit, at the left (2). (c) The earliest vertical aerial photograph of this area, taken in April 1941. (d), (e) and (f) show the outlet channel cutting into the sand plain, shifting the tidal delta and extending the sand spit. (Picture (a) taken by C.D.H. Pilkington, courtesy of Miss V. Pilkington; (b) taken by S. Fowler (negative A2/556), used with permission of CSIRO Archives; (c) Copyright © Royal Australian Air Force; (d) Copyright © Commonwealth of Australia, Geoscience Australia; (e) Copyright © Crown (State of Victoria) 1981; (f) Copyright © Parks Victoria.)

Cooper (1958) was the first author to draw attention to the fact that an alien species could change the morphology of local dune landscapes. He reported that **Ammophila arenaria*, indigenous to western Europe and the Mediterranean and introduced to California in 1869, had formed prominent foredunes where none existed before. In Australia, this species was introduced in 1883 to stabilise the drifting dunes near Port Fairy, Victoria, and was widely used along temperate shores (Molineux 1902). On Wilsons Promontory it was first used in 1915 (Garnet 1971, Crawford 1984) and in the 1950s the Soil Conservation Authority tested this and another foreign species, **Thinopyrum junceiforme*, together with *Spinifex sericeus* and two other native species, for their sand-binding characteristics, at Tongue Point at the southern end of Waratah Bay (SCA 1960). However, only **Ammophila arenaria* was used during dune restoration work in the 1960s and 1970s at Sandy Point and the parking area at the inlet (SCA, pers. comm. 1983).

Methods

Between November 1980 and October 2003, I visited the spit 15 times. Fieldwork initially focused on general description and mound formation, and later on assessing dune and vegetation development. Observation sites were marked on airphotos or sketch maps and documented with photos from approximately standard positions. For ease of identification I gave names to features on the spit, often inspired by location or based on their age (Fig. 1c).

Mounds formed by the wind resistance of a single plant are sometimes called 'nebkas' or 'biogenic mounds' (e.g. Danin 1996, Hesp and McLachlan 2000), but I just use 'mounds.' 'Dune ridge' and 'dune field' refer to land forms where such mounds have coalesced. Botanical nomenclature follows Walsh and Entwisle (1994–1999) except in the case of *Senecio lautus*, which name has been replaced by *Senecio pinnatifolius* (Belcher 1994). Specific epithets have been used for all species except for *Acacia longifolia* var. *sophorae*, for which the varietal name has been substituted. Scientific names for mammals follow Triggs (1996), those for birds Christides and Boles (1994). Asterisks precede the names of introduced species.

After I became aware of the history of the spit, I obtained copies of maps and airphotos, spoke to local inhabitants and searched in libraries and archives for information on early vegetation development. The oldest useful picture, taken in 1927, shows a view over the mouth of Shallow Inlet from a high dune (Fig. 2). The oldest aerial photo is an oblique view

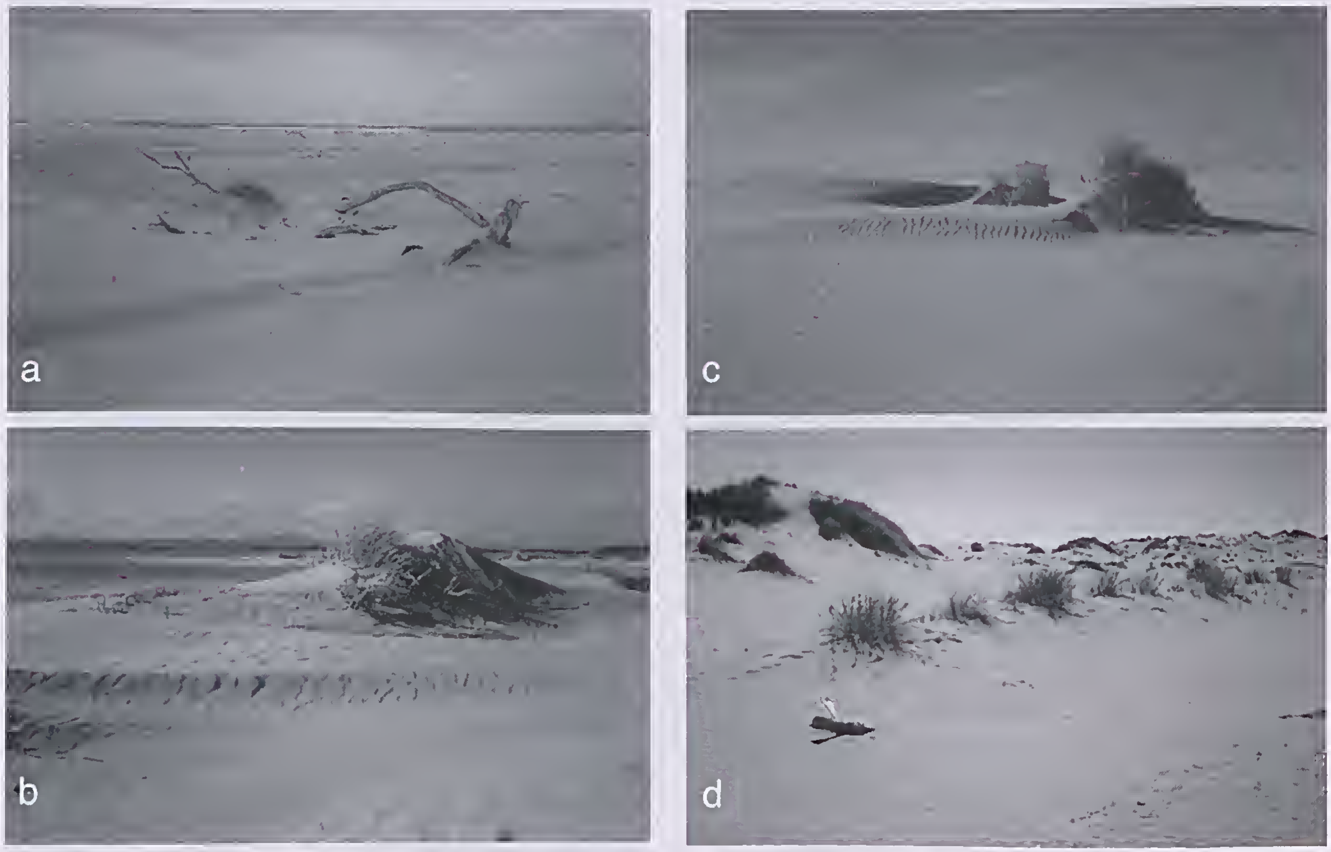


Fig. 3. Examples of mound and ridge formation by pioneer grasses. (a) Start of a **Thinopyrum junceiforme* mound around a piece of flotsam. (b) A mound established in *Spinifex sericeus*, with the highest point behind the plant. (c) Wind-shadow ridges formed behind *Austrofestuca littoralis* tussocks. (d) A low ridge formed in *Austrofestuca littoralis* tussocks along a flotsam line at the foot of the dune field.

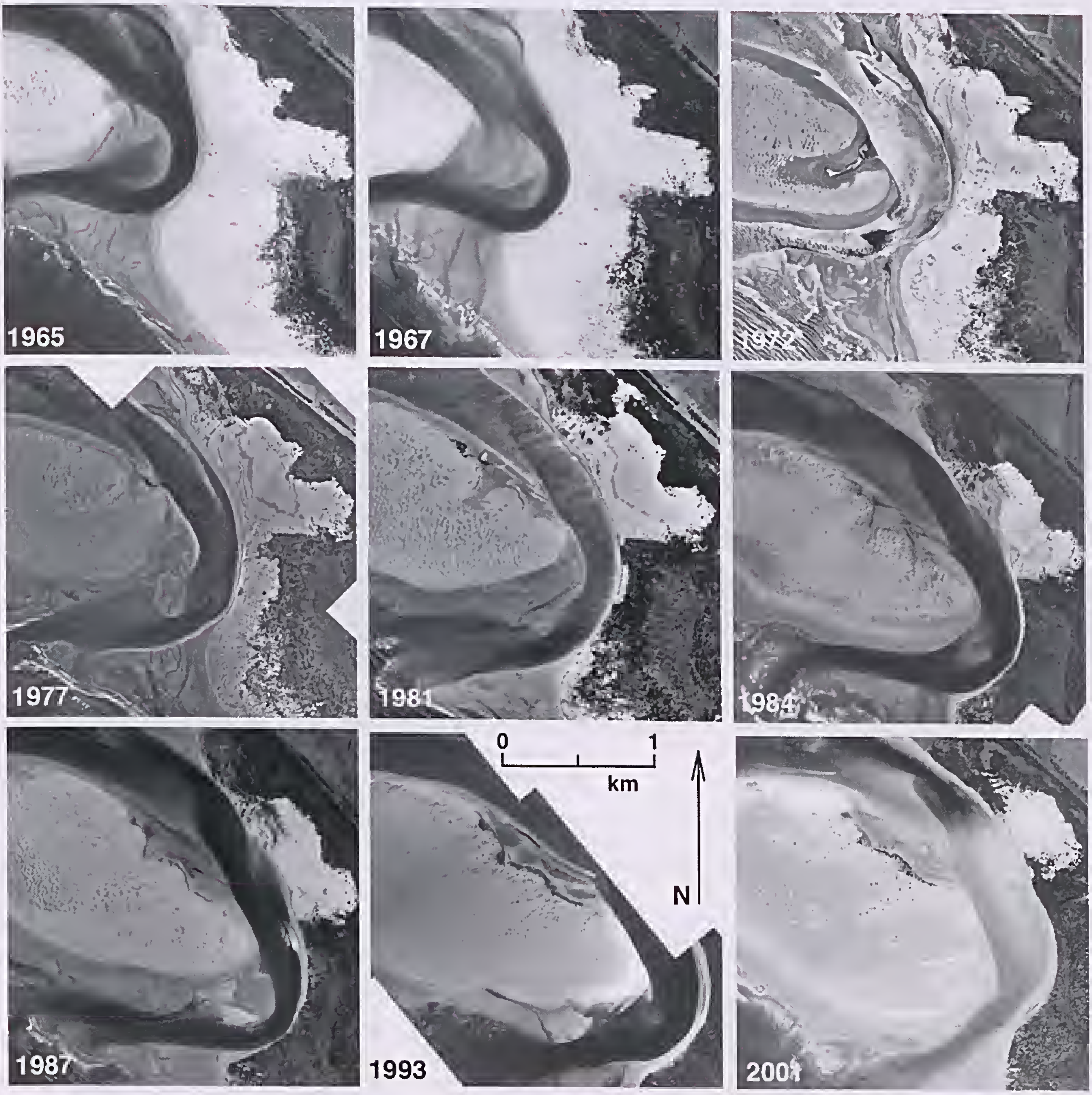


Fig. 4. Growth of the sand spit between 1965 and 2001. Nine sections from airphotos have been chosen to illustrate the successive phases of this process. The first, from 1965 to 1972, is one of substantial growth with the formation of a 'mini-spit' and a tidal 'mini-bay.' During the following years sand was mainly deposited towards the tip of this mini-spit. The mini-spit tip-growth cycle was repeated several times during the 1970s and early 1980s, although much narrower corridors were left between the newer and older parts. Later in the 1980s and during the 1990s deposition increased towards the mouth of Shallow Inlet as currents began to erode the north-east side of the spit tip. The total area added to the spit since 1965 is about 1.77 km^2. (1965 photograph Copyright © Commonwealth of Australia, Geoscience Australia; 1967 photograph courtessy of W.G. Tuddenham; 1972, 1977, 1981, 1984, 1987 and 1993 photographs Copyright © Crown (State of Victoria); 2001 photograph Copyright © Parks Victoria.)

Table 1. Vegetation of the dunes along Waratah Bay.

The table is a combination of transect and time sequences to show the general vegetation pattern from the upper beach to the rear of the high dune. Data obtained in 1983 along a track across the dunes (now named 'Access Point 6') form the basis for the table and are in bold. Data from the 1990s have been added in normal font. Observations made at the spit end of the high dune are indicated by italics. Where they were made as a transect sequence, the year of observation has been added. Without a year they refer to occasional records. - Species names are followed by a letter coding the mode of dispersal: a: wind, h: water, z: birds, mammals, ants, ?: unsure. - Abbreviations in the other columns indicate commonness: f: few; s: some, several, scattered; r: rather common; c: common; d: (co)dominant; p: in poor condition.

		YOUNGER DUNE RIDGES							OLDER DUNE RIDGE											HIGH OLD DUNE RIDGE					
		outer ridge	*2003 outer ridge*	**seaward slope (Cs)**	seaward slope	new ridge (D)	**outer ridge (C)**	*1980 foredune ridge*	**outer ridge (C) swale**	*2003 middle ridge*	*young ridge of mounds*	*1980 foredune swale*	**middle ridge (B)**	*2003 inner ridge*	former seaw. slope (Cs)	former outer ridge (C)	**inner ridge (A)**	*2003 inner lee slope*	**irregular inner zone**	**lower frontal slope**	**upper frontal slope**	*wind-shorn scrub margin*	**crest area**	**lee slope**	*open patches in scrub*
Herbaceous component																									
**Cakile maritima*	h	s	r	s	s		s		p		s		p		s										
**Thinopyrum junceiforme*	h	d	d	d	d	d	d	d	p	p	p	p	p	p	r										
Spinifex sericeus	a,h			s	r	d	r	s	c	s		s	d	s	d	d	r								
Austrofestuca littoralis	h			s			s	s	s	s	s	s		s		s		s							s
Actites megalocarpa	a							s		s	s	s	s	r	r	s									s
Carpobrotus rossii	z								s						s	s	s	s	s	s				s	s
**Senecio elegans*	a								s			s			s	s	s	s	s	s					
**Euphorbia paralias*	h									s	s			c	c			c							
Stackhousia spathulata	a									s	r	s				s									s
**Lagurus ovatus*	a								s							r	s		c	s	s				r
**Hypochoeris radicata*	a													c	r	s	s								
Isolepis nodosa	a,h													s	s	r	s		c	c					
Poa poiformis	a												s			r	s		c	c					
Agrostis avenacea	a								s				s												
Epilobium billardierianum	a														s	s									
Senecio pinnatifolius	a														s					s					
Lepidosperma gladiatum	?																				c				s
Bryophytes	a																		r	c	s				
Woody component																									
Ozothamnus turbinatus	a								s	s	s	s	s	r	s	c	s	s	s	p		s			
Olearia axillaris	a								s			s	s	s	s	s	s	s	p	f	s	s	s		
Acacia sophorae	z													s	s	r	s	r	s	c		s	s	s	
Olearia glutinosa	a														s	s		s	s	f		s			
Leptospermum laevigatum	a,z														s	s		f	r	c	d	c	d	d	
Leucopogon parviflorus	z															r	s		p	c		s	d	d	
Exocarpos strictus	z															s			s			s	s	s	
Olearia phlogopappa	a														s					f	c		s	f	
Correa alba	z?																			r	s	s			
Banksia integrifolia	a																						s	s	
Clematis decipiens	a																						f	s	
Allocasuarina verticillata	a																				s				
Myoporum insulare	z																				s				
Pomaderris oraria	z?																				c				
Rhagodia candolleana	z																				c				
Tetragonia implexicoma	z																				s				
Number of species		2	2	4	3	2	4	4	10	7	7	8	8	10	17	18	11	9	13	15	12	8	8	7	6

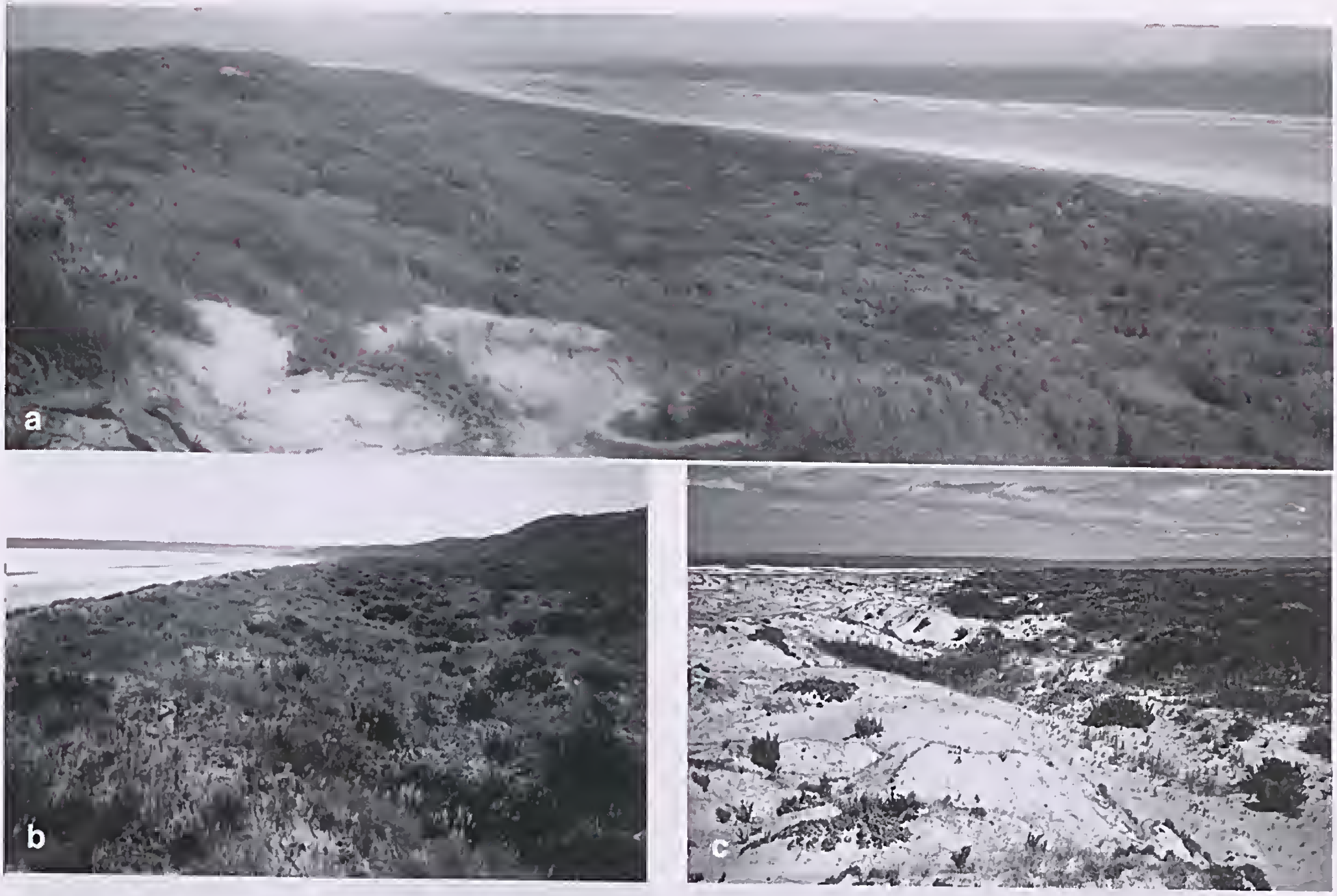


Fig. 5. Dune ridges along the high dune ridge of Waratah Bay. (a) The view in September 1990 from the frontal slope of the high ridge along the dune ridges formed since the 1950s. (b) A 1996 view over the rear slope of the youngest ridge which was formed after 1983 and is dominated by *Spinifex sericeus* with scattered **Thinopyrum junceiforme*, *Actites megalocarpa*, **Euphorbia paralias*, and young shrubs of *Ozothamnus turbinatus* and *Olearia axillaris*. The shrubs in the swale are older; *Ozothamnus turbinatus*, up to 1.2 m tall, is the most common one. Young individuals of *Leptospermum laevigatum*, *Leucopogon parviflorus* and *Exocarpus strictus* are present, too. On the seaward side, the irregular crest of the youngest ridge is dominated by **Thinopyrum junceiforme*. (c) A southwesterly view in 2003 over the dune ridges at the end of the high dune ridge. The young, 'moundy' ridges are dominated by **Thinopyrum junceiforme*, the scrub on the older ones by *Acacia sophorae*. This species is also the more common coloniser of the swales behind the younger ridges.

of the entrance taken in 1937; the earliest vertical photographs date from 1941. Since 1965 the spit and its environs appear on airphotos of a variety of scales. 23 sets of photos were available, the latest dated 14 April 2001 but unfortunately, although they are informative about geomorphological development, recognition of vegetation is hampered by its sparse cover and overexposure of the sandy substrate.

Results – Geomorphological dynamics

Sand spit growth

The shoals in the mouth of Shallow Inlet are formed through the interacting forces of ebb and flow on the sandy sediments. Just before and after high water the eroding power of the currents in the main channel impinges most strongly on the outer bend of the meander and is often increased by wave action in the west-facing exit channel. The shore here has been eroding at an average rate of about 50 m/y (J. Whelan, pers. comm.; author's obs.). The sand thus removed largely remains in circulation in the lower reaches of the delta and is augmented with sand brought in by longshore currents. Until the early 1990s major sedimentation was predominantly along the northeastern side of the spit, but then gradually shifted to the southeastern shore. This process is described in the caption of Fig. 4. In summary, spit growth has been episodic and, as will be discussed later, this is still recognisable in the present dune landscape.

Initiation of mound building

The spit is exposed to the full force of the wind and sand is constantly moving, even under moderately windy conditions (see Bourman 1986). Although the shallow groundwater table keeps large areas near saturation point, the wind still dislodges sand grains and concentrates these into phalanxes of shallow ridges. These ridges slowly advance over the

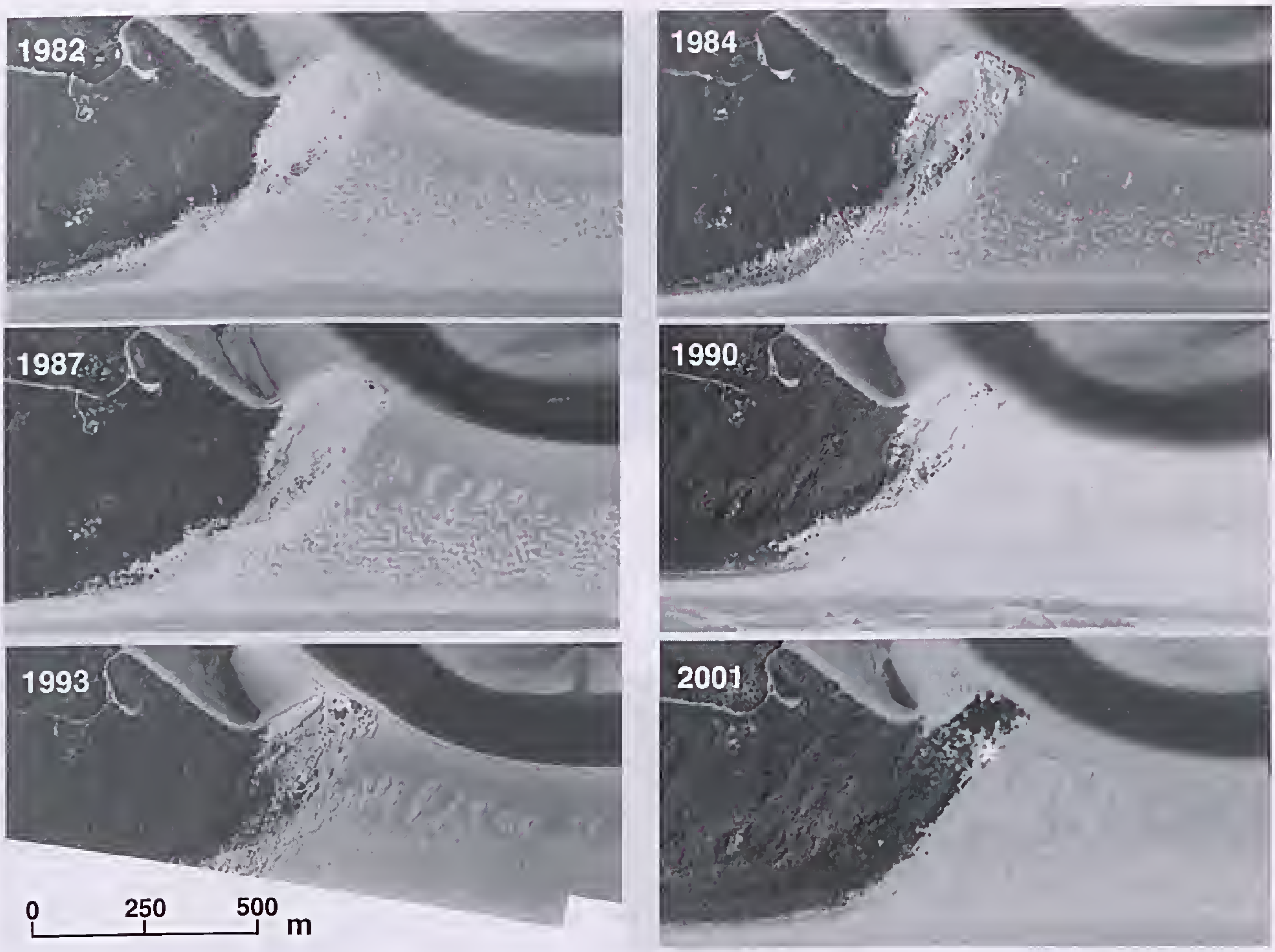


Fig. 6. The development of a series of ridges along the inlet side at the base of the spit as shown by aerial photographs. The photos also show the formation of and succession on the ridges at the southern end of the high dune ridge. The area to the east of the densily vegetated high dune was successfully stabilised by the Soil Conservation Authority with **Ammophila arenaria* in the 1970s. It provided a vantage point (marked *) for the views shown in Fig. 7. (1982, 1984, 1987 and 1993 photographs Copyright © Crown (State of Victoria); 1990 and 2001 photographs Copyright © Parks Victoria.)

moist surface and change according to variations in wind speed and direction. They form the intricate patterns often seen on airphotos. Flooding high tides, which inundate low-lying areas and on occasions even flow across the spit, erase lower ridges and their build-up begins anew.

Few species are able to cope with these harsh conditions. In order of decreasing significance they are the grasses **Thinopyrum junceiforme*, *Austrofestuca littoralis*, **Ammophila arenaria* and *Spinifex sericeus* and the sea rocket **Cakile maritima*. Seeds and rhizome fragments arrive in flotsam carried onto the spit by spring and storm tides. Here they face an uncertain future. Once germinated or sprouted, young plants may be dislodged through wind erosion or buried under sand for too long to survive. When they begin to grow, they interrupt the surface flow and sand begins to accumulate among and around the shoots. In contrast to pioneer species growing in strand lines on beaches backed by dunes, on the spit plants are sparsely spread.

Due to strong winds, the mounds accumulating in the grasses attain a more or less conical shape. Wind gullies form at the foot of the windward slope and along the sides of the mounds, while some of the eroded sand accumulates at the rear. Erosion at the windward side often exposes roots with the result that growth is usually limited to the crest and upper part of the lee slope. The inlet shore lies somewhat sheltered from the strongest impact of the westerlies and only there low wind-shadow ridges are formed (Fig. 3c). Their shape is partly determined by the wind regime and partly by the growth-form of the species: compact for *Austrofestuca littoralis*, **Ammophila arenaria* and **Cakile maritima* and spreading for **Thinopyrum junceiforme* and *Spinifex sericeus* (Heyligers 1985).

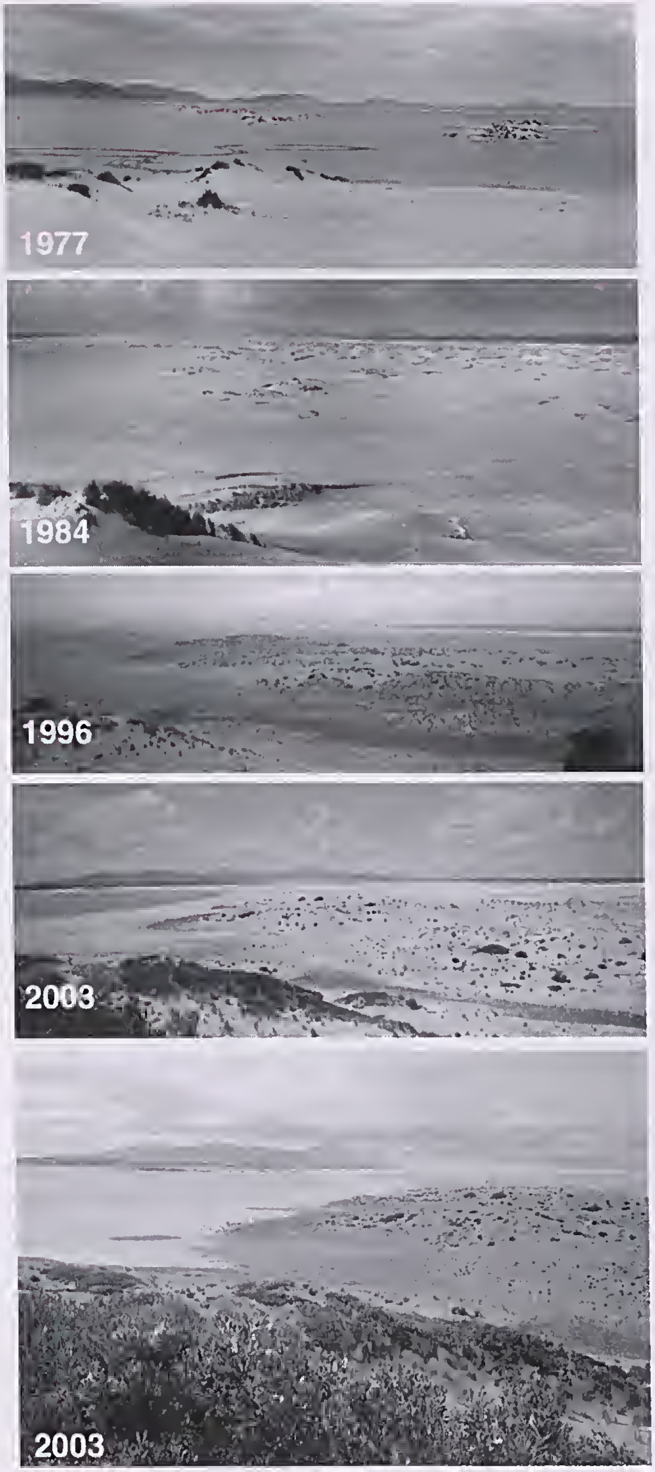


Fig. 7. The development of the ridges at the base of the spit as shown by pictures taken from a high ridge at the base of the spit (see asterisk on 2001 photo, Fig. 6). These pictures show the growth and coalescence of the **Thinopyrum junceiforme* mounds along the inlet shore. The 'dark spots' are mostly patches of *Actites megalocarpa*, others young *Ozothamnus turbinatus* bushes. The mounds in the background of the 1984 view are bare sand ripples which move over the spit at the mercy of changes in wind direction. The second 2003 view shows the scene at incoming tide, with a young **Thinopyrum junceiforme* patch still above water and the *Thinopyrum* fringe along the tips of the older ridges. (The 1977 picture taken by and courtesy of J. Whelan.)

Influence of episodic spit growth

During phases of slow spit growth the position of the upper beach changes little, while in periods of more rapid growth it gradually shifts in tandem with the progressing shoreline (Fig. 4). Consequently, sand deposition on the upper beach is also subject to variation. When the upper beach remains relatively stationary for a few years, more sand is deposited on it than when it gradually shifts, resulting in slight variations in relief. This is crucially important for mound and dune formation. Firstly, higher sections have a greater probability of 'catching' flotsam and propagules; secondly, stranded objects are more or less aligned with the shape of the former upper beach and, thirdly, a slightly higher elevation enhances the survival rate of seedlings. Hence, the resulting mounds and ridges mark episodes of little progress in spit growth and provide a means for assigning approximate formation dates for the dune fields (Fig. 1c).

Vegetation

Vegetation succession on the dune ridges adjoining the high dune of Waratah Bay has followed a 'classical' pattern and provides a context for the discussion of this process on the spit. This is followed by a short section on the formation of ridges on the base of the spit near the inlet, before I deal with the various aspects of vegetation colonisation and dune development on the spit plain.

Dune ridges near the eastern end of the Waratah Bay high dune

Along the shore of Waratah Bay, after a period of erosion along the foot of the old, 20 m high dune ridge, progradation took over and new foredunes were formed. This process was well under way in the 1960s (Smith 1968) and by the early 1980s three ridges and a zone of a rather less distinct topography separated the high dune from the upper beach (Fig. 5a).

The woody vegetation on the high dune is windshorn and only 2–3 m high on the crest and seaward slope, but increases in height to 4–6 m on the back slope. *Leptospermum laevigatum* and *Leucopogon parviflorus* are dominant in the fairly well closed canopy (Table 1). *Banksia integrifolia*, *Exocarpos strictus* and *Acacia sophorae* are of lesser importance but *Clematis decipiens* is locally common. *Lepidosperma gladiatum* is the only species regularly present in the ground cover. More species occur at the seaward side, where *Acacia sophorae* is more common.

In 1983 the outer dune ridge (C) was 10 m wide with the crest 2 m above upper beach level. It was covered by **Thinopyrum junceiforme* and some *Spinifex sericeus* (Table 1). In the depression at the rear were *Ozothamnus turbinatus* and *Olearia axillaris* shrubs up to 0.3 m tall. *Spinifex sericeus* was dominant on the next ridge (B), also 10 m wide but half a metre higher. Apart from some spindly

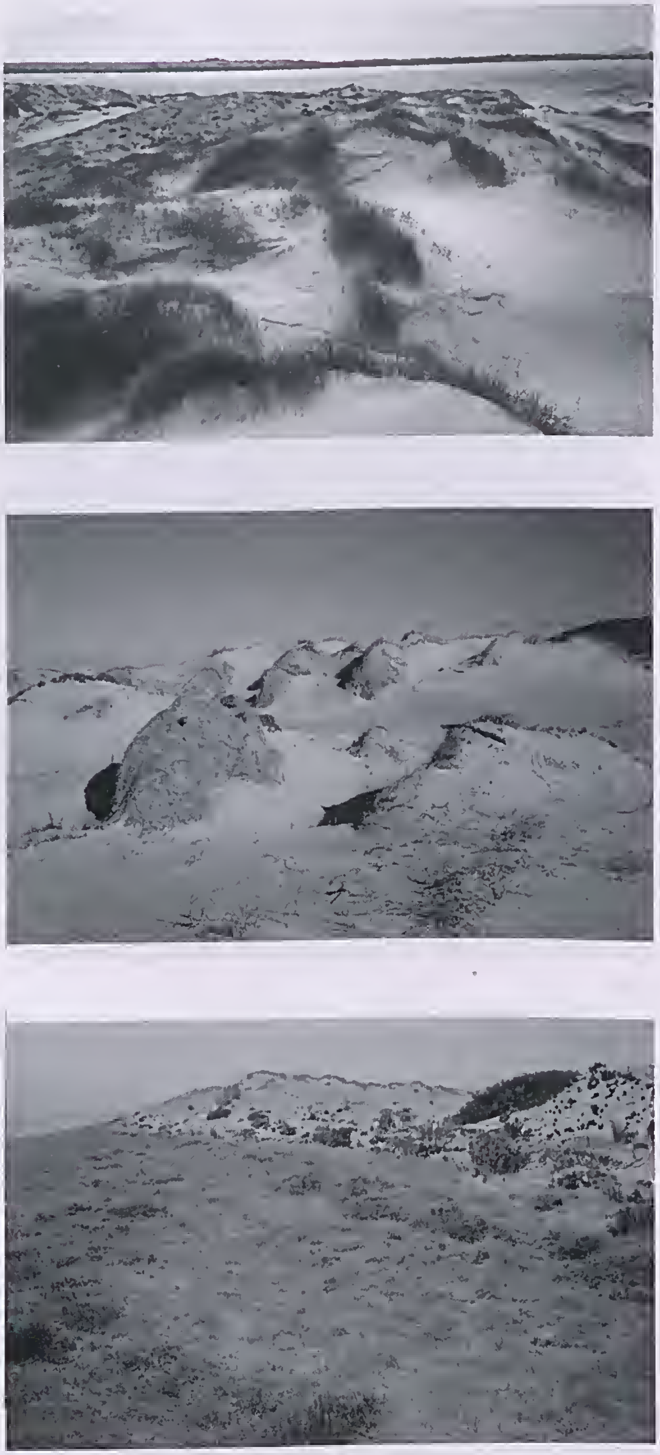


Fig. 8. Pictures, taken in 2003, of the oldest ridge at the base of the spit, (a) over the highest crest of the three amalgamated ridges; (b) from the side, showing the very irregular relief and the pronounced banding of **Thinopyrum junceiforme*; (c) of the *Thinopyrum* fringe formed in flotsam lines with scattered *Suaeda australis* plants on the highest ones. Scattered young *Ozothamnus turbinatus* bushes and, higher up, a sprawling young *Acacia sophorae* grow among *Carpobrotus rossii*, **Euphorbia paralias*, *Stackhousia spathulata* and *Actites megalocarpa* on the sheltered lower slope of the ridge.

**Thinopyrum junceiforme* and scattered young *Ozothamnus turbinatus* and *Olearia axillaris*, few other species were present. In the next 1 m deep swale *Ozothamnus turbinatus* was common, about 2 m tall, with tops more or less level with the wind profile over the adjoining ridges. The crest of the inner ridge (A) was 3 m above upper beach level and in width similar to the other ridges. There was no **Thinopyrum junceiforme*, the *Spinifex sericeus* cover was more open and some *Isolepis nodosa* had come in; there were scattered *Ozothamnus turbinatus* and *Olearia axillaris*, 0.8 m tall, and an occasional young *Leptospermum laevigatum*, 0.3 m tall, while low *Acacia sophorae* was spreading from the shrubbery on the back slope.

The zone of irregular topography between ridge A and the high dune probably represents an older ridge and swale topography, more or less obliterated by blowout erosion. It was covered with rather impenetrable shrubbery, 2 m high, in which *Acacia sophorae*, *Leptospermum laevigatum* and *Leucopogon parviflorus* were codominant. *Ozothamnus turbinatus* and *Olearia axillaris* were still common at the seaward side, but further in their vigour strongly declined, indicative of an age gradient in the formation of this zone.

By 1993 a new ridge (D) had accumulated in **Thinopyrum junceiforme* and some *Spinifex sericeus* (Table 1; Fig 5b). It extended the foredune zone by 20 m and was still lower than ridge C. On the crest and back slope **Thinopyrum junceiforme* had already lost much of its vigour due to dwindling nutrient availability, but not so on the seaward slope, where it merged into a zone of **Cakile maritima* mounds on the upper beach, together forming a 14 m wide scree slope. The narrow depression behind ridge D was obliterated in places by sand from partial 'blow-throughs.' There the first shrubs of *Ozothamnus turbinatus*, *Olearia axillaris* and *Olearia glutinosa* appeared and there was more *Spinifex sericeus* than on the crest. These young shrubs were also present on the 10 m wide frontal slope and crest of ridge C (Fig. 5b). On this ridge **Thinopyrum junceiforme* was now in a poor condition, but the cover of *Spinifex sericeus* had increased. The vegetation on the back slope and in the swale had been taken over by *Ozothamnus turbinatus* and *Olearia axillaris*. A dense, 2.2 m high shrubbery of *Ozothamnus turbinatus*, *Olearia axillaris*, *Acacia sophorae*, *Leucopogon parviflorus* and *Olearia glutinosa* covered ridge B, continued over ridge A and joined the scrub in the zone with irregular topography. In summary, over a period of about ten years succession had shifted the vegetation communities of the ridges one ridge seaward.

At the southeast corner of the high dune the orientation of the ridges changes to west-east (Fig. 6). Exposed to a larger fetch and therefore increased sand supply, their topography becomes rather irregular. The newer

Thinopyrum ridges here began as strings of mounds formed by plants that successfully established in flotsam deposits aligned on high tide marks. Later, the mounds gradually merged into ridges (Fig. 5c). On the older ones some *Spinifex sericeus* and *Austrofestuca littoralis* occurred among the **Thinopyrum junceiforme*, especially on lee slopes, and were joined by *Actites megalocarpa*, *Stackhousia spathulata* and young *Ozothamnus turbinatus*, *Olearia axillaris* and *Acacia sophorae* in the swales (Table 1).

Dune ridges on the base of the spit near the inlet shore

During the 1970s, at the base of the spit, several **Thinopyrum junceiforme* patches became established along the upper shoreline of the inlet. By the early 1980s they had formed eight small mound complexes, separated by groundwater-saturated sand flats (Figs. 6 and 7). Over time, the complexes increased in size and gradually built into a series of irregular ridges. Initially they were kept apart by wind channelling over the intervening flats, but as their height and width increased the channels began to fill in. Thus the three ridges closest to the base of the spit merged and by 2003 sand accumulation between the next three ridges had raised the surface of the flats well above groundwater level. In 1993 ridge height varied from 2.5 m to 4.0 m, in 2003 from 4.8 to 7.2 m with the highest parts usually at the windward side.

**Thinopyrum junceiforme* has been the major ridge builder and forms bands across the crests and down the sides of the ridges (Fig. 8). Species other than the hardy *Actites megalocarpa* only got a chance to establish on the somewhat less exposed ridges closest to the high dune (Table 2). *Stackhousia spathulata*, *Ozothamnus turbinatus* and *Olearia axillaris* were the first to come in, followed by *Austrofestuca littoralis*, *Isolepis nodosa* and a few others, including a single *Acacia sophorae*. As yet, no *Spinifex sericeus* has been seen. Plant cover remained open, but widespread spindly **Thinopyrum junceiforme* shoots show that their rhizomes are still the main stabiliser of the dune surface. In 2003 the number of young *Ozothamnus turbinatus* shrubs had noticeably increased and the oldest shrub was now 3 m tall, had a spread of 6 m and was much sanded up in its centre.

Table 2. Vegetation of the ridges at the inlet side of the base of the spit
Ridges have been numbered (in bold) starting with the ridge closest to the high dune.
Species names are followed by a letter coding the mode of dispersal: a: wind, h: water, z: birds, mammals, ants.
Abbreviations in the other columns indicate commonness: 1: 1 plant, 2, 3: 2 or 3 plants, f: few; s: some, several, scattered; r: rather common; c: common; d: (co)dominant; j: juvenile; p: plants in poor condition.

		RIDGE NUMBER AND SAMPLE YEAR											
	Mode of dispersal	**4** 1993	**4** 2000	**3** 1993	**4** 2003	**3** 2000	**3** 2003	**2** 1993	**2** 2000	**1** 1993	**1** 2000	**2** 2003	**1** 2003
Herbs, including grasses													
**Thinopyrum junceiforme*	h	d	d	d	d	d	d	d	d	d	c,p	c,p	c,p
Actites megalocarpa	a			1	f	s	f	f	s	f	rc	c	c
Stackhousia spathulata	a							s	s	2	c	rc	rc
Austrofestuca littoralis	h							s	s	1	s	s	s
**Hypochoeris radicata*	a									3	1	f	f
**Cakile maritima*	h							s,j		s	s		
Epilobium billardierianum	a										1, j	f,j	f
**Euphorbia paralias*	h										1, j	f	f
Isolepis nodosa	a,h										1	1	1
Carpobrotus rossii	z											s	s
Agrostis avenacea	a									1			
**Sonchus oleraceus*	a										1		
Shrubs													
Olearia axillaris	a					1		f,j	f,j	s,j			
Ozothamnus turbinatus	a						2,j	2	4	1	s	3	c
Acacia sophorae	z										1		f
Atriplex cinerea	h												1
Number of species		1	1	2	2	3	3	7	6	9	12	10	13

Table 3. Vegetation of the dune field fringes along the margin of Shallow Inlet: species presence.
Species names are followed by a code for mode of dispersal: a: wind, h: water, z: birds, mammals, ants, ?: unsure.
Species presence is listed on a 10 – 1 scale; 10: always present; 1: occasionally present. Values of 8 and higher are in bold. Overall presence in the last column shows in how many of the ten groups the species is present.

Group number		**1**	**2a**	**2b**	**2c**	**2d**	**3a**	**3b**	**4a**	**4b**	**5**	
	mode of dispersal	*Thinopyrum* fringes	Youngest *Thinopyrum* vegetation	Young *Thinopyrum* vegetation	Older *Thinopyrum* vegetation	Oldest *Thinopyrum* vegetation	*Isolepis* vegetation, some shrubs	*Isolepis* vegetation, more shrubs	*Spinifex-Isolepis* vegetation	*Spinifex-Isolepis* veg. with older shrubs	*Ozothamnus-Olearia* vegetation	**Overall presence**
Shrubs												
Ozothamnus turbinatus	a	1	3	5	7	**10**	4	**9**	**9**	**10**	**10**	10
Olearia axillaris	a	1	4	6	**9**	**9**	5	**9**	**10**	**10**	**8**	10
Olearia glutinosa	a		4	4	**10**	**9**	5	**8**	**9**	**10**	7	9
Acacia sophorae	z		1	1	4	1		**8**	**8**	**8**	2	8
Leptospermum laevigatum	a,z							1	4	**10**		3
Leucopogon parviflorum	z							2	3	4		3
Exocarpos strictus	z							1	1	1		3
Rhagodia candolleana	z									3		1
Olearia phlogopappa	a									1		1
Grasses												
**Thinopyrum junceiforme*	h	**10**	**10**	**10**	**10**	**10**	1	3	4	5	4	10
Austrofestuca littoralis	h	2		7		7	4	3	5	5	6	8
Spinifex sericeus	a,h	1		6		**10**	5	6	**10**	**9**	6	8
**Ammophila arenaria*	h			1		1		6	5	4		5
**Lagurus ovatus*	a		2	1	**9**	3	5	**9**	6	6	2	9
Agrostis aemula	a		3	1	**9**		4	4	4	6	2	8
Poa poiformis	a				1		4		3			3
Herbs with high overall presence												
Isolepis nodosa	a,h	1	6	6	7	**9**	**10**	**10**	**10**	**10**	6	10
Carpobrotus rossii	z	1	1	4	4	7	6	**8**	**8**	**9**	2	10
Actites megalocarpa	a		5	7	**9**	7	5	**8**	6	6	**9**	9
**Melilotus indica*	?		**8**	7	**9**	**9**	6	**9**	**9**	**8**	6	9
Stackhousia spathulata	a		3	4	3	**9**	4	3	4	6	**9**	9
**Sonchus oleraceus*	a		7	7	7	**9**	4	4	1	6	2	9
Clematis decipiens	a		3	1	6	6	3	**9**	6	**10**	1	9
**Senecio elegans*	a		6	4	6	7	5	7	6	6	1	9
Epilobium billardierianum	a		4	3	4	7	5	4	3	1	3	9
**Conyza bonariensis*	a		3	1	3	6	4	1	3	6	1	9
**Hypochoeris radicata*	a		1	4	3	4	4	2	5	5	1	9
**Cakile maritima*	h,z	7	3	3	1	4	1	1			2	8
**Pseudognaphalium luteoalbum*	a		2	6	3	4		2	1	1	1	8
Senecio pinnatifolius	a		3		4	4	3	2	3	5	1	8
**Euphorbia paralias*	h		1	3	1	1	3	3	6	1		8
Other herbs												
Comesperma volubile	a		1		4	4	1	7		4	1	7
Senecio biserratus	a		5	1	3	6	3	2		1		7
Sonchus hydrophilus	a		3	3	3		1	1	1	1		7
**Cirsium vulgare*	a			3	1	4	1			1	2	6
**Hypochoeris glabra*	a			1		3		1	1	1	1	6

Group number		1	2a	2b	2c	2d	3a	3b	4a	4b	5	
	mode of dispersal	*Thinopyrum* fringes	Youngest *Thinopyrum* vegetation	Young *Thinopyrum* vegetation	Older *Thinopyrum* vegetation	Oldest *Thinopyrum* vegetation	*Isolepis* vegetation, some shrubs	*Isolepis* vegetation, more shrubs	*Spinifex-Isolepis* vegetation	*Spinifex-Isolepis* veg. with older shrubs	*Ozothamnus-Olearia* vegetation	**Overall presence**
Acaena novae-zelandiae	z					1	4	2	3	3		5
Microtis uniflora	a				1		3	4	1	1		5
**Leontodon taraxacoides*	a			1	1	1		1		1		5
Apium prostratum	h?			1	1	4		3				4
Chrysocephalum apiculatum	a			1		1				3	1	4
Centaurium* spp	a?						1	1	1		1	4
Apalochlamys spectabilis	a		1			1	1			1		4
Suaeda australis	h	4	1									2
Sarcocornia quinqueflora	h	3	1									2
Galium australe	z					1		2	1			2
Scaevola calendulacea	z						1			1		2
Bryophytes	a		1	1	1		3		1	1		6
Number of samples		11	10	7	7	7	8	9	8	8	9	

The following species, found only once, have been left out: *Limonium australe* (h,1), *Atriplex billardieri* (h,1), *Carex pumila* (h, 2d), *Paspalum vaginatum* (h, 3a), *Oxalis corniculata* (?, 4a),**Taraxacum officinale* (a, 4a), **Anagallis arvensis* (?, 4b), **Arctotheca calendulacea* (a,z, 4b) and *Crassula decurrens* (?, 4b).

**These *Centaurium* species are **C. erythraea* and **C. tenuiflorum*.

Dune and vegetation development on the spit plain

The formation of dune fields at the inlet side of the spit plain began during the early 1960s and ended in the 1980s (Figs. 1e and 9). It happened in phases as a consequence of the episodic expansion of the spit (Fig. 4). During times of slow spit extension the increasing height of the upper beach along the inlet shore provided favourable conditions for mound building. Following the curve of the beach, the mounds formed an arc-shaped configuration, broadest at the northern end, thinning to a narrow row at the other. **Thinopyrum junceiforme* was the major mound and subsequent dune builder in the broad part, **Ammophila arenaria* was prevalent in the narrower 'tail.' During periods of more rapid spit growth conditions for mound formation ceased and only reoccurred when spit growth slowed again. Thus a series of five dune fields developed, separated by low corridors, before currents in the main channel washed out the next incipient field and diverted the main accretion of the spit towards the mouth of Shallow Inlet. This lead in the 1990s to the formation of an almost linear east-west oriented dune ridge about 450 m away form the dune fields. **Austrofestuca littoralis* and **Thinopyrum junceiforme* were the main dune builders. A repeat of this process began in 2003 with an incipient ridge on a slight, irregular rise with groups of low *Thinopyrum* mounds and one small *Austrofestuca* mound about 120 m from and parallel to the previous ridge.

With a long fetch over the spit and hence an ample supply of sand, the dune fields increased in height and volume and, starting at the plain side, the corridors between the fields were gradually filled in. After 30–40 years dune crests of older sections were 10–13 m high and the fields had become one continuous nearly 2 km long, broad ridge from which tail ridges extended onto the plain (Figs. 10 & 11). Initially, **Thinopyrum junceiforme* was the dominant coloniser, but later was joined by the other pioneer grasses. The prominence of **Ammophila arenaria* in the tail ridges is likely due to increased availability of fresh groundwater as these sections are situated towards the somewhat higher centre of the spit (Fig. 11). For the same reason **Ammophila arenaria* also established at several spots along the foot on the plain side of the dune fields and thus became part of the fields.

The crests and windward slopes of the fields have a very irregular relief due to the wind resistance of the grass-covered mounds. Apart from the grasses, *Actites megalocarpa* is the only other species that manages to grow on the windward side of the dunes, but in the lee of the mounds suitable niches occur for the establishment of *Stackhousia spathulata*, *Olearia axillaris* and *Ozothamnus turbinatus*. The latter proves to be especially hardy and is able to cope with sand burial by quick-growing shoots. Thus, it contributes to dune building and occurs on some of the highest crests (Fig. 10a). Because the vegetation on the crests and windward slopes remains very open, the dune fields are at best semi-stabilised and, locally in the older fields, erosion has deflated mounds and flattened relief.

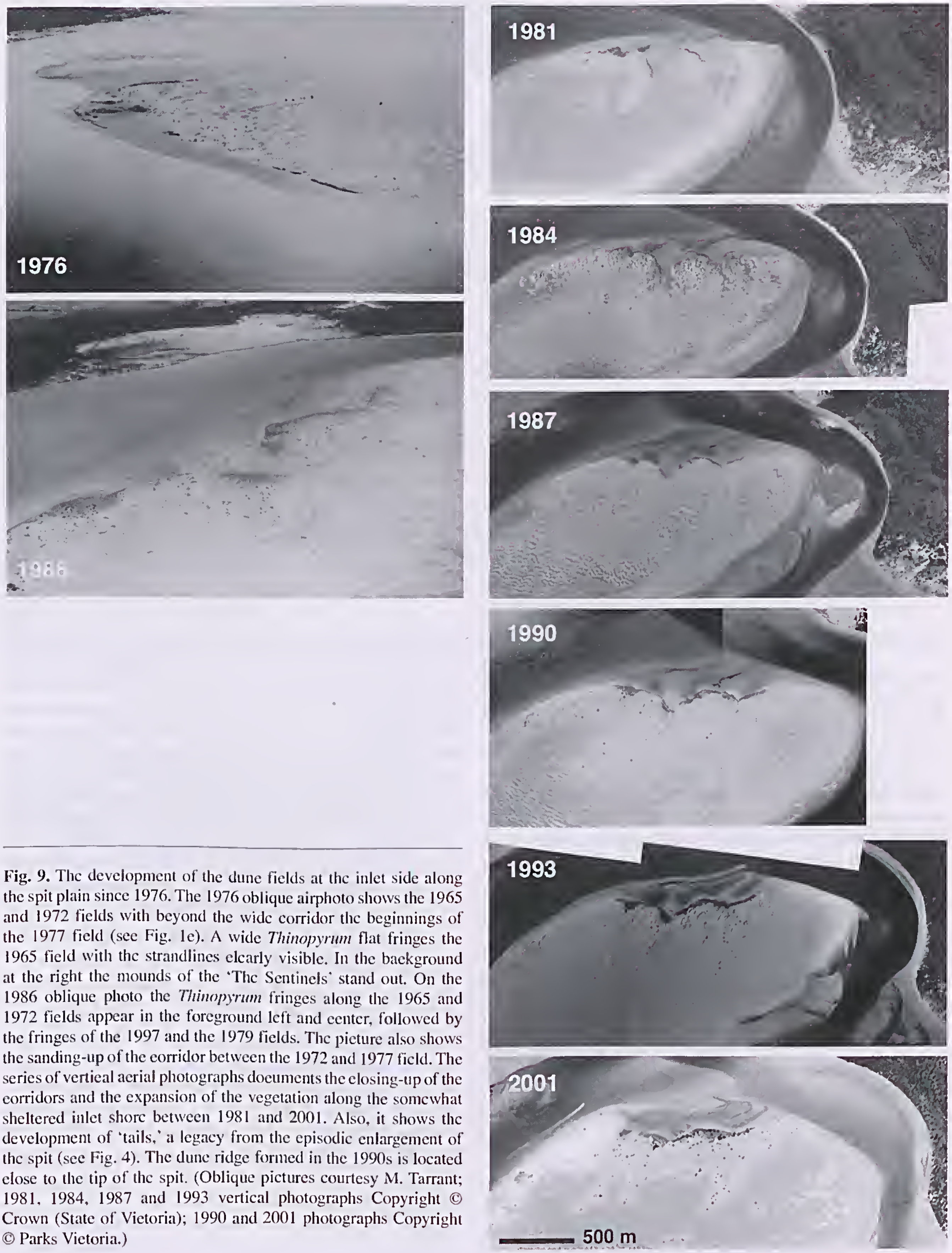


Fig. 9. The development of the dune fields at the inlet side along the spit plain since 1976. The 1976 oblique airphoto shows the 1965 and 1972 fields with beyond the wide corridor the beginnings of the 1977 field (see Fig. 1e). A wide *Thinopyrum* flat fringes the 1965 field with the strandlines clearly visible. In the background at the right the mounds of the 'The Sentinels' stand out. On the 1986 oblique photo the *Thinopyrum* fringes along the 1965 and 1972 fields appear in the foreground left and center, followed by the fringes of the 1997 and the 1979 fields. The picture also shows the sanding-up of the corridor between the 1972 and 1977 field. The series of vertical aerial photographs documents the closing-up of the corridors and the expansion of the vegetation along the somewhat sheltered inlet shore between 1981 and 2001. Also, it shows the development of 'tails,' a legacy from the episodic enlargement of the spit (see Fig. 4). The dune ridge formed in the 1990s is located close to the tip of the spit. (Oblique pictures courtesy M. Tarrant; 1981, 1984, 1987 and 1993 vertical photographs Copyright © Crown (State of Victoria); 1990 and 2001 photographs Copyright © Parks Victoria.)

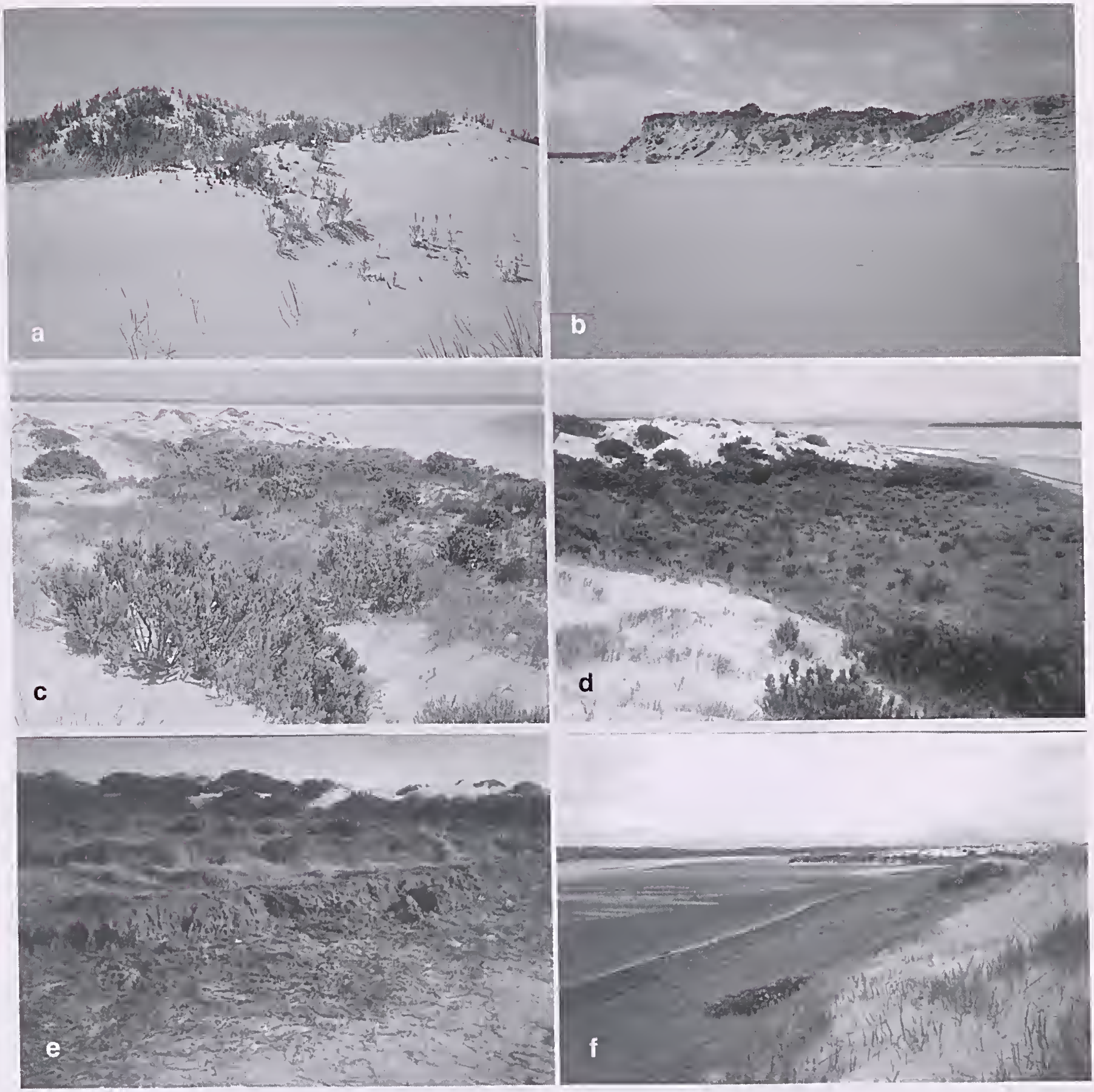


Fig. 10. Views of the vegetation of the older part of the dune field. (a) Crest dominated by *Ozothamnus turbinatus*; (b) eroded north-east side of the 1965 field, with slip slopes up to 8 m high, at low tide; (c) dune hollow above this section seen from a crest, with *Spinifex sericeus*, *Isolepis nodosa* and *Actites megalocarpa* common in the groundcover and up to 2 m tall *Ozothamnus turbinatus* shrubs (vegetation group 4a); (d) the flat between the 1965–1972 sections with **Thinopyrum junceiforme* and *Isolepis nodosa* ground cover and scattered young shrubs of *Ozothamnus turbinatus* and *Olearia axillaris* up to 0.5 m tall (vegetation group 2d); (e) the inlet side of the flat with a large amount of dead seagrass deposited in the outer margin of the flat during the last king tide; the ridge further in, with the vigorous **Thinopyrum junceiforme* growth, resulted from a similar previous event (vegetation group 1) (see also the 1976 view in Fig. 9); (f) *Thinopyrum* fringe of the 1972 field with the fringe of the 1977 field in the background; outgoing tide has exposed the wide tidal flat. **Thinopyrum junceiforme* declines in vigour towards the slope, which is lightly covered by *Spinifex sericeus*; the patch in the foreground is a flowering *Actites megalocarpa* 'tussock' (vegetation group 2e) [(a), (b) and (c) taken in 2003, (d) and (f) in 1993 and (e) in 1994].

Table 4. Vegetation of the dune field fringes along the margin of Shallow Inlet: species commonness and condition. Species names are followed by a letter coding the mode of dispersal: a: wind, h: water, z: birds, mammals, ants; ?: unsure. Commonness and/or condition is coded as follows: do: (co)dominant, vc: very common, co: common, rc: rather common, lc: locally common, s: several, scattered or some, f: few, 1: one plant, 2, 3: two, three plants; j: juvenile, v: vigorous, p: (very) poor condition, d: dead. Overall presence shows in how many of the ten groups the species is present.

Group number		**1**	**2a**	**2b**	**2c**	**2d**	**3a**	**3b**	**4a**	**4b**	**5**	
	mode of dispersal	*Thinopyrum* fringes	Youngest *Thinopyrum* vegetation	Young *Thinopyrum* vegetation	Older *Thinopyrum* vegetation	Oldest *Thinopyrum* vegetation	*Isolepis* vegetation, some shrubs	*Isolepis* vegetation, more shrubs	*Spinifex-Isolepis* vegetation	*Spinifex-Isolepis* vegetation with older shrubs	*Ozothamnus-Olearia* vegetation	**Overall presence**
Shrubs												
Ozothamnus turbinatus	a	f, j	s, j	s, j	s j–1 m	1–s <1.0 m	s j	s–co 1.0–2.2 m	1–s p	f–vc <2.5 m	s–co 0.5–2 m	10
Olearia axillaris	a	1, j	s, j	s, j	s j	s–rc <0.6 m	s–co j	s–co 0.6–1.7 m	1–s <1.7m	s–co <1.9 m	s–co 1.0–2.0 m	10
Olearia glutinosa	a		s, j	s, j	1–co j–1.2 m	1–s <0.7 m	rc–co j	1–co 0.4–1.8 m	f–co <2 m	s–co <1.9 m	s–co 1.0–2.0 m	9
Acacia sophorae	z		1, j	1, j	1, j	1, 0.5		1–s 0.6–2.5 m	1–f low–3 m	s–co 1.6–4.0 m	1 or 2 0.6 m	8
Leptospermum laevigatum	a,z							1, 1.2 m	1, j	1–s,<2.5 m		3
Leucopogon parviflorum	z							1–s, 1.5 m	f, <1.9 m	1, 1.7 m		3
Exocarpos strictus	z							1, 1.2 m	1, 0.5 m	1, 0.7 m		3
Rhagodia candolleana	z									1, < 0.5 m		1
Olearia phlogopappa	a									1, 0.7 m		1
Grasses												
**Thinopyrum junceiforme*	h	do, v	do, v–p	do, p	do, p	do, v–p	p	p	v p	p	s, p	10
Austrofestuca littoralis	h	s		f–s		f–rc	1–f	s	s	f	s	8
Spinifex sericeus	a,h	s		s–rc		f–s	s	s–rc	s–do	f–co	s–do	8
**Ammophila arenaria*	h			s		1		s	s–co	f		5
**Lagurus ovatus*	a		1, s	f	s–vc	lc, co	s–rc	s–lc	co	co–vc	co	9
Agrostis aemula	a		f	f	f–rc		1–f	s	s	s–co	s	8
Poa poiformis	a				1		s		s–rc			3
Herbs with high overall presence												
Isolepis nodosa	a,h	2	s–co	f–rc	f–lc	f–rc	co–do	co–do	lc–co	rc–co	s–co	10
Carpobrotus rossii	z	1, v	s, j	f–s	1–s	f	s	s	s	f–lc	f	10
Actites megalocarpa	a		s–co	rc	f–rc	rc	f–rc	s–rc	s	s	s	9
**Melilotus indica*	?		s–co	s–co	f–co	s–vc	s–co	s–co	s–do	s–co	co–vc	9
Stackhousia spathulata	a		s–co	s–co	s	s–co	s–lc	rc	co	f	s–co	9
**Sonchus oleraceus*	a		f–co	s–co	1–vc	f–co	s–co	s	co	f	f, vc	9
Clematis decipiens	a		lc	s	f	s	1, rc	s–do	f–co	s–lc	f	9
**Senecio elegans*	a		s	1–f	s	s–co	s–rc	s	s–co	f–lc	1	9
Epilobium billardierianum	a		s	lc	s–vc	s	s	s	f	s	s	9
**Conyza bonariensis*	a		s	s, co	s, co	s	s	f	s	f–s	1	9
**Hypochoeris radicata*	a		s	f	f	f	s	f	f–s	f–vc	f	9
**Cakile maritima*	h,z	s	f	1	f	1–f	s	f			1–f	8
**Pseudognaphalium luteoalbum*	a		f	f	s	s		f	f	f	f	8
Senecio pinnatifolius	a		s–lc		f	f	s	f	s,co	s–co	f	8
**Euphorbia paralias*	h		rc	1–s	1	1, p	f	s–lc	s–lc	1		8

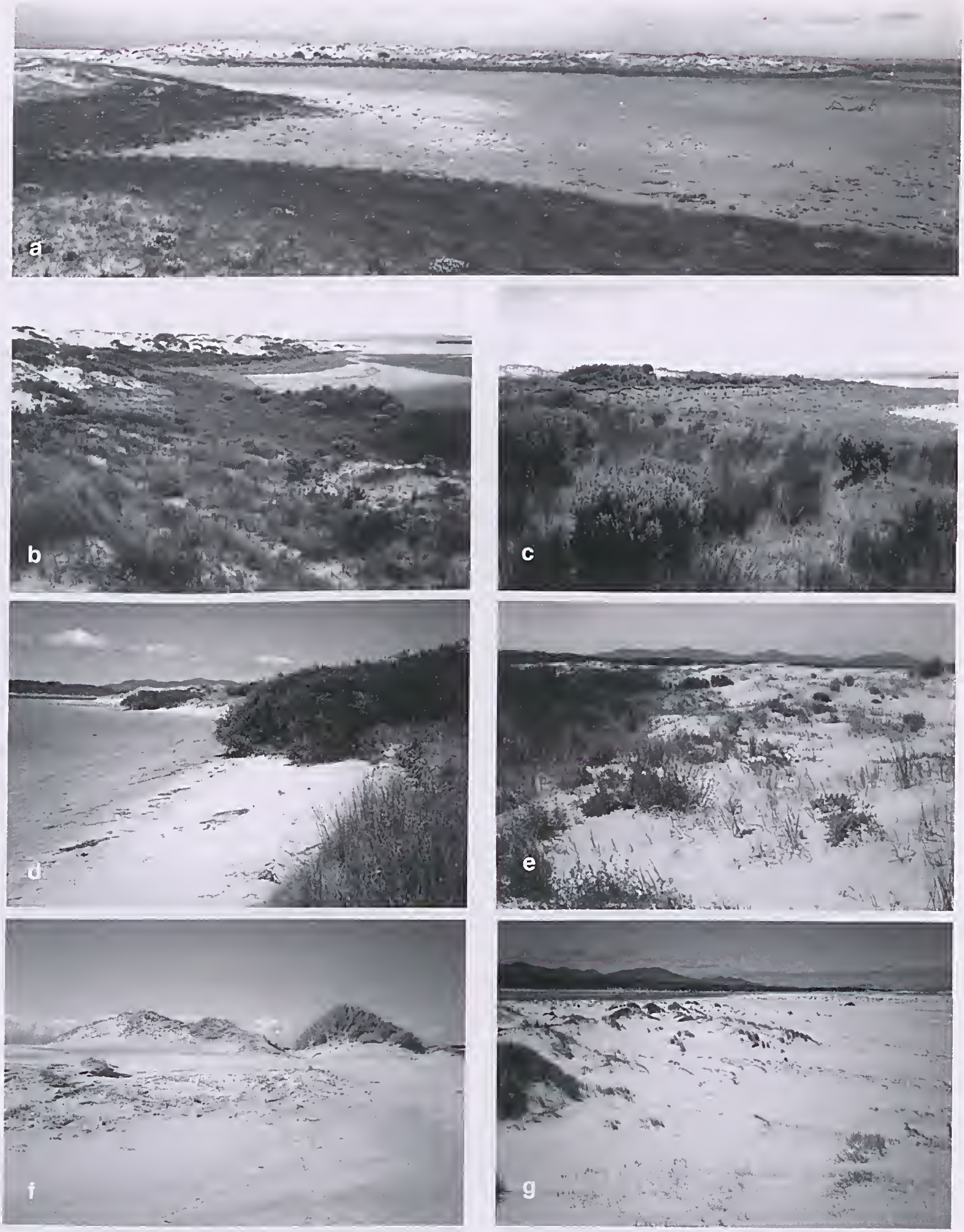
Group number		1	2a	2b	2c	2d	3a	3b	4a	4b	5	
	mode of dispersal	*Thinopyrum* fringes	Youngest *Thinopyrum* vegetation	Young *Thinopyrum* vegetation	Older *Thinopyrum* vegetation	Oldest *Thinopyrum* vegetation	*Isolepis* vegetation, some shrubs	*Isolepis* vegetation, more shrubs	*Spinifex-Isolepis* vegetation	*Spinifex-Isolepis* vegetation with older shrubs	*Ozothamnus-Olearia* vegetation	**Overall presence**
Other herbs												
Comesperma volubile	a		1	1–s	f	3	s–co			f	co	7
Senecio biserratus	a		s	f	f	s	1, f	f		s		7
Sonchus hydrophilus	a		f–rc	s, co	f		f	co	f	co		7
**Cirsium vulgare*	a			1, f	f	1–f	1			f	f	6
**Hypochoeris glabra*	a			f		f		f	f	s	f	6
Acaena novae-zelandiae	z					f	s–co	s	s–lc	s		5
Microtis uniflora	a				lc		s	l–s	s	s		5
**Leontodon taraxacoides*	a			f	f	f		f		f		5
Apium prostratum	h?			f	1	f		f				4
Chrysocephalum apiculatum	a			f		f				f	f	4
**Centaurium* spp.	a?						f	f	f		1	4
Apalochlamys spectabilis	a		2			2	d			d		4
Suaeda australis	h	s	p									2
Sarcocornia quinqueflora	h	s	p									2
Galium australe	z					s		lc	f			2
Scaevola calendulacea	z						1			1		2
Bryophytes	a		f	f	s		s		lc	lc		6
Average number of species/sample		3	9	12	15	20	12	17	16	20	10	
Range of number of species/sample		1–6	7–15	10–18	11–18	14–29	10–15	12–24	14–21	13–26	6–18	

In 1981 the most striking element on the spit plain was an isolated group of *Ammophila* mounds, hence named 'The Sentinels,' together with a nearby 'Outlying Sentinel' (Fig. 12a). They represent the oldest tail ridge. Over the years the mounds of the group gradually coalesced notwithstanding a great deal of wind-gullying retarding this process. By 2003 they had formed a short ridge, 165 m long 50 m wide and 7.5 m high, with a 30 m wide footslope. The Outlying Sentinel, a metre or so lower, 38 m long and 30 m wide, was connected to the main group by a low, bare rise, 60–70 m wide and 1.5 m high. Some wind-borne propagules of *Ozothamnus turbinatus*, *Actites megalocarpa* and *Stackhousia spathulata* had found suitable niches among the **Ammophila arenaria* leaves, but no other species had become established.

Ten years after its formation started in the 1990s, the incipient ridge near the end of the spit had developed into a 400 m long dune with a 35 m gap between a section dominated by *Austrofestuca littoralis* and one where **Thinopyrum junceiforme* was dominant (Fig. 13). In 2003 the crests in the *Austrofestuca littoralis* part were up to 5 m high, but much lower in the **Thinopyrum junceiforme* section, except for a 3.6 m high **Ammophila arenaria* mound and some *Spinifex sericeus* mounds up to 4 m high. Strong wind-gullying caused the ridge to be very 'moundy' and apart from the four grass species and an odd **Cakile maritima* plant along the foot, no other species were present.

The vegetation of the sheltered areas along the inlet side of the dune field

Flotsam, mainly dead seagrass from the inlet shallows, washes up on the beach along the dune fields, either as strandlines or covering wider areas in sheltered nooks resulting from the filling in of corridors. In these deposits **Thinopyrum junceiforme* forms a dense sward of lush fertile shoots (Figs. 10 and 11). Over time, as sand and more flotsam gets caught along the margin, a low ridge develops, a process that is repeated when another band of flotsam is deposited on the beach. In time, low-lying '*Thinopyrum* flats' are formed on which the former strand lines are still traceable as low ridges (Fig. 10e).


a
b
c
d
e
f
g

Although the flats are sheltered from direct impact of westerly winds, they are affected in various ways by sand carried beyond the dune fields. If the dunes are high, sand precipitates as slip slopes, which encroach on the flats and choke the vegetation in their progress. When the dunes are lower, sand tends to accumulate along the inner margin of the flat thus creating a transition zone of irregular relief between dune and flat (Fig. 11e). The flats are the least exposed habitat on the spit; consequently, their vegetation is richer in species than elsewhere. The only other sheltered habitat occurs in a hollow on the highest area of the oldest dune field (Fig. 10c). Its vegetation is similar to that of the flats.

I have sorted my vegetation records of the sheltered sites into ten groups (Tables 3 & 4). Criteria have been dominance of **Thinopyrum junceiforme* and *Isolepis nodosa*, presence of *Spinifex sericeus* and *Austrofestuca littoralis*, and number and age of shrubs. Many of the other species are wind-dispersed annuals or biennials. They form a large random element and contribute little to criteria for classification. Presence of mosses adds to surface stablisation and accretion (Moore & Scott 1979, Danin 1996, Danin *et al.* 1998), but I have not been consistent in recording moss occurrence and the tables give an incomplete picture of their importance. Two common species are *Tortula princes*, known to be tolerant to saltspray (Moore & Scott 1979) and *Bryum caespiticium*.

Group 1, *Thinopyrum* fringes, comprises the pioneer vegetation on the upper beach. These fringes may be only a metre or so wide along slopes but are usually wider, especially near and in the nooks of closed-up corridors. **Thinopyrum junceiforme* is very vigorous and, in contrast to elsewhere on the spit, flowers profusely. **Cakile maritima* and some saltflat species may occur too, while *Spinifex sericeus* stolons may spread from adjacent dunes (Figs. 8c, 10e, 11a and b).

Groups 2a to 2d, *Thinopyrum* vegetation, represent areas where **Thinopyrum junceiforme* is still an important component of the ground cover, although in 2a it is already less vigorous and its condition in the other groups is often 'spindly' or poor. This provides an opportunity for other species to establish, longer-lived ones such as *Isolepis nodosa* and *Actites megalocarpa*, and annuals such as *Agrostis aemula*, **Lagurus ovatus*, **Melilotus indica* and **Senecio elegans*. *Sonchus hydrophylus* is a characteristic species for this vegetation group. The main criteria for recognising four groups have been the occurrences of *Spinifex sericeus*, *Austrofestuca littoralis* and the annual grasses together with the increasing presence and size of *Olearia glutinosa*, *Olearia axillaris* and *Ozothamnus turbinatus*. *Acacia sophorae* is the only other woody species that is becoming established. *Isolepis nodosa* and *Actites megalocarpa* are frequently present in the ground cover. Species richness increases from an average of 9 species per sample in 2a to 20 in 2d (Figs. 10d, 10e and 11a).

Groups 3a and 3b, *Isolepis* vegetation, are characterised by the prevalence of *Isolepis nodosa*, while **Thinopyrum junceiforme* is usually absent. In most samples of group 3a one or two shrub species are present, but their occurrence in group 3b is much more pronounced as shrubs are generally larger and more numerous. *Acacia sophorae* is often present and, in a few samples, *Leucopogon parviflorus* too. Group 3a has on average 12 species per sample, 3b 17. Noteworthy among these is *Clematis decipiens*, which is often found as patches on the ground. *Carpobrotus rossii* is another common member of the group.

Groups 4a and 4b, *Spinifex-Isolepis* vegetation, can be regarded as a parallel of groups 3a and 3b. The main differences are the common occurrence of *Spinifex sericeus* and an increase in the number of shrub species, with *Leptospermum laevigatum* being the most important one. The difference between 4a and 4b is a reflection of the increasing richness of the shrub component although the vegetation structure is still open shrubland. *Olearia axillaris* and *Olearia glutinosa* are generally less than 2 m tall, while *Ozothamnus turbinatus* may grow to 2.5 m, before they begin to decline in vigour. Many *Leptospermum laevigatum* shrubs were still small, but the oldest ones were up to 2.5 m high. The oldest *Acacia sophorae* was 4 m tall and had grown out to a width of 20 m. *Leucopogon parviflorus* remains more localised. *Isolepis nodosa*, *Clematis decipiens* and *Carpobrotus rossii* are important components in the ground cover. Group 4a has on average 16 species per sample, 4b 20 (Figs. 10c, 11c and e).

Fig. 11. The later dune fields. (a) A 1984 view of the corridor between the 1972 and the 1977 field, of which the *Thinopyrum* fringe occupies the foreground, with *Stackhousia spathulata* where the grass cover thins out (vegetation groups 1 and 2a). On the slope of the 1972 field a large area with about 2 m tall *Ozothamnus turbinatus* shrubbery with some *Olearia glutinosa* (vegetation group 5). (b) The same view in 2000; in the foreground the lee slope of the 1977 field with vegetation dominated by *Spinifex sericeus* and *Isolepis nodosa* and a terrace in the middleground with *Isolepis* vegetation (vegetation groups 4a and 3a, respectively). Along the inlet margin some *Acacia sophorae* and *Ozothamnus turbinatus*, about 2 m tall. (c) A 1993 view of the flat between the 1977 and the 1979 fields with, in the foreground *Spinifex-Isolepis* vegetation with scattered, about 1.2 m tall shrubs of *Ozothamnus turbinatus*, *Olearia axillaris*, and *Olearia glutinosa* (vegetation group 4b). (d) By 2003 erosion was destroying the terrace along the 1979 field thus undermining the low-growing, but wide *Acacia sophorae* bushes. (e) The irregular lee slope of the younger section of the fields in 1993, with an open vegetation of *Spinifex sericeus*, *Austrofestuca littoralis*, *Isolepis nodosa* and *Stackhousia spathulata* (vegetation group 4a), and the adjacent terrace with *Acacia sophorae*. (f) The last mounds of the younger fields; the *Spinifex sericeus* mound at the left is 5.5 m high, the **Ammophila arenaria* mound at the right 6 m. (g) View over the end of the younger fields, showing the very pronounced relief resulting from wind action on the **Thinopyrum junceiforme* mounds; in the background the dune ridge formed in the 1990s ((f) and (g) taken in 2003).

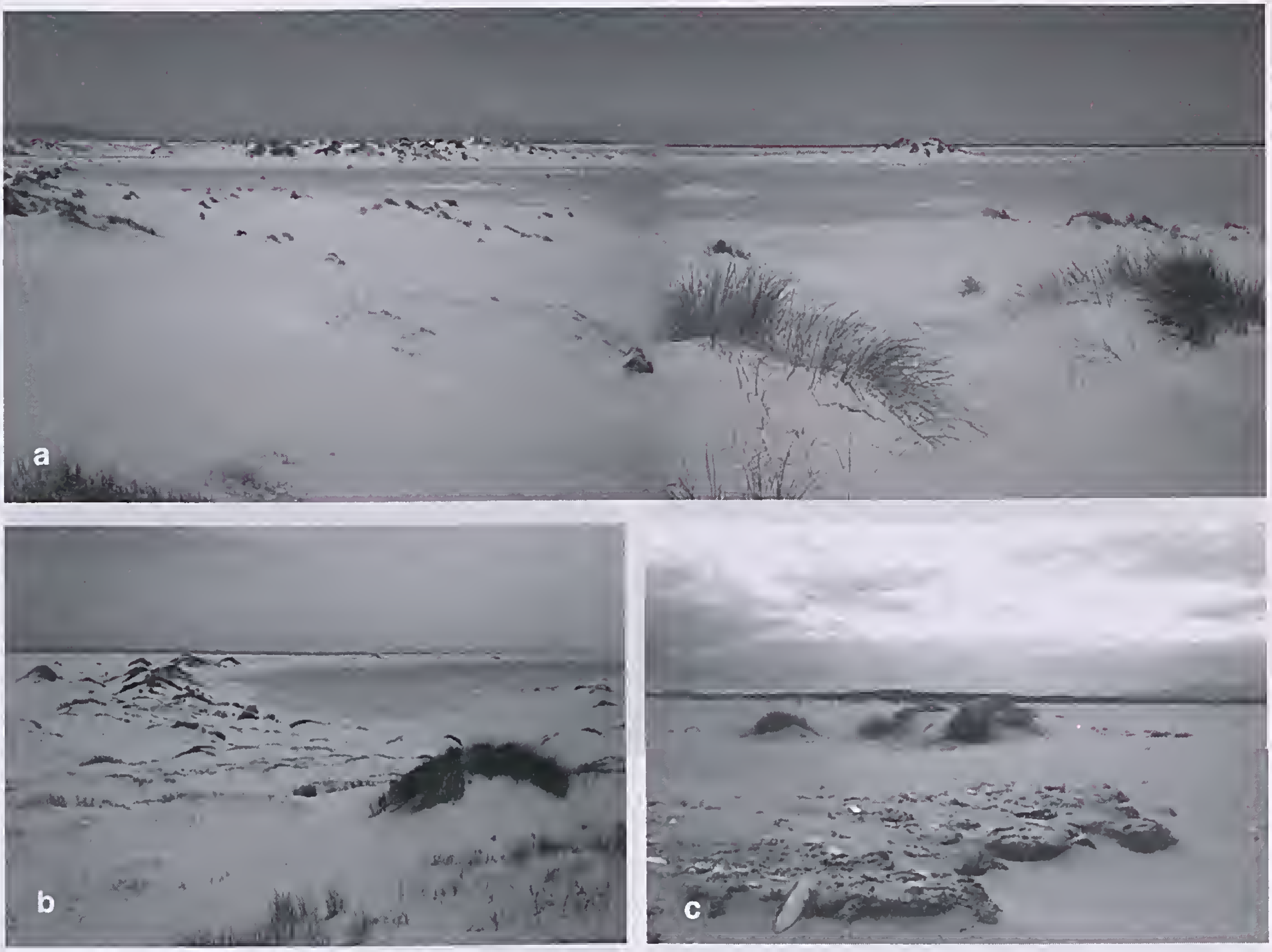


Fig. 12. Dune field tail ridges. (a) 'The Sentinels,' tail ridge of the 1965 field, accumulated in **Ammophila arenaria* over a period of 40 years; the tail ridge of the 1972 field is located further away at the left (picture taken in 2003). (b) and (c) Two aspects of the tail ridge of the 1979 field photographed in 1993; (b) seen from the dune field, showing **Ammophila arenaria* mounds and lower **Thinopyrum junceiforme* mounds, (c) the **Thinopyrum junceiforme* mounds at the end of the tail with an eroded, sanded-up flotsam deposit in front.

Group 5, *Ozothamnus-Olearia* vegetation, represents the transition from the vegetation of the dune field crests to that of the older flats (Fig. 11a). *Ozothamnus turbinatus*, *Olearia axillaris* and *Olearia glutinosa* are the species that determine the aspect as the ground layer is usually sparse. *Actites megalocarpa* and *Stackhousia spathulata* are its prominent members, species which are also present on the exposed aspects of the dunes, thus pointing to the ecotonal nature of group 5. On average there are 10 species per sample.

In general, the groups represent increasing age and complexity of the vegetation but this does not necessarily imply that topographically or over time the groups follow sequentially. The best examples of succession are to be found at the large corridor nooks between the three older dune field sections (Fig. 11 a and b). There the relief shows the position of former *Thinopyrum* fringes (Group 1) indicative of the gradual expansion of the vegetated area, thus creating zones of older vegetation and increasing species richness (Groups 2a–2d). Over this gradient the vigour of **Thinopyrum junceiforme* decreases and with an increasing importance of *Isolepis nodosa* the succession leads to the vegetation classified as Groups 3a and 3b. Where *Isolepis* vegetation with some shrubs (Group 3a) developed along the younger dune field sections it may be transformed into *Spinifex-Isolepis* vegetation (Groups 4a and 4b) where sand accumulates as irregular 'tongues' over areas with *Isolepis* vegetation. Such 'edaphic succession' does not occur along the margins of higher older sections, where spillover slopes advance over the flats. There, succession proceeds to *Isolepis* vegetation with more shrubs (Group 3b) if not cut short in the mean time through burial by the encroaching avalanche of sand.

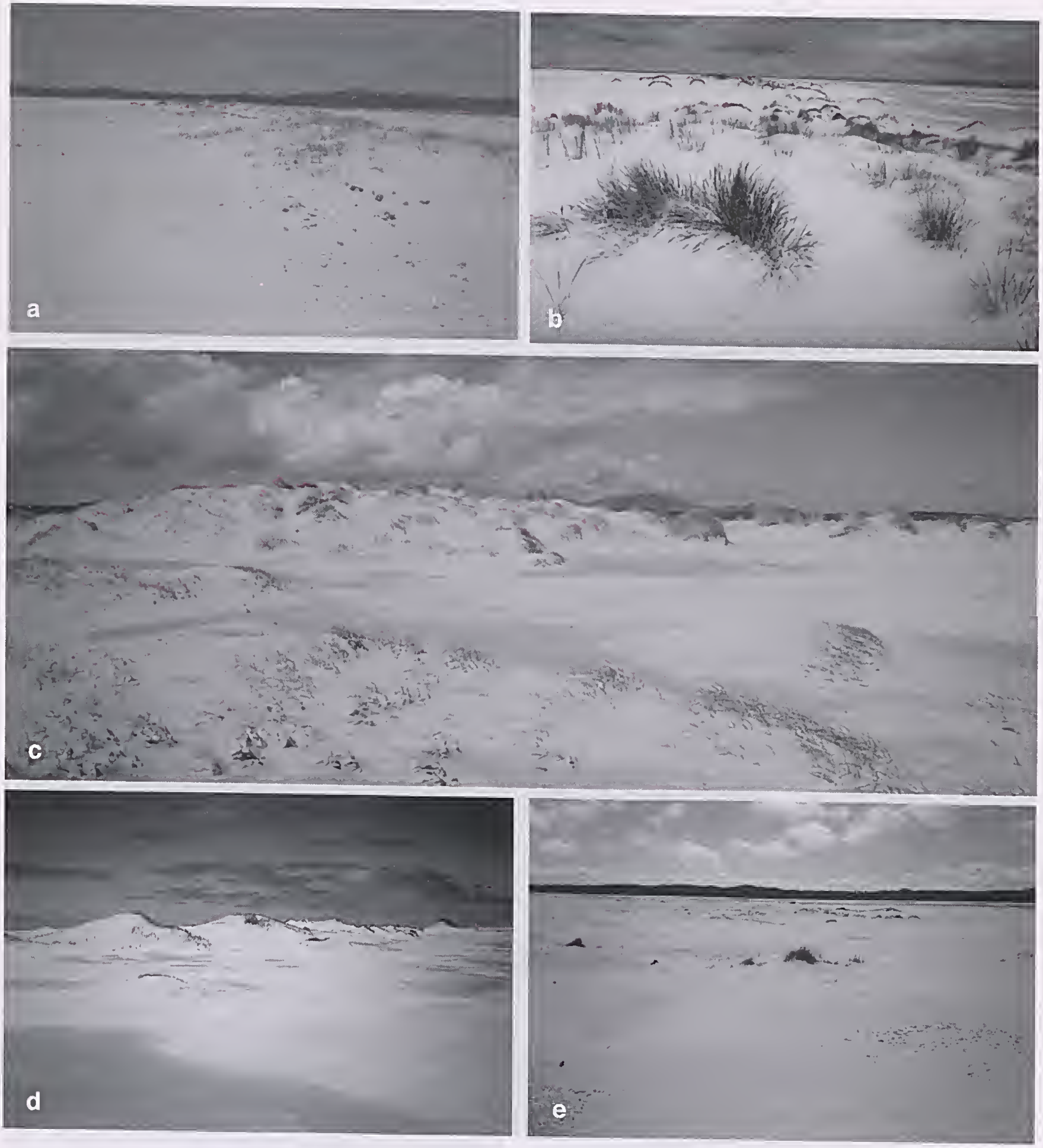


Fig. 13. The new dune ridges, (a) to (d) show the 1990 dune ridge, (e) the incipient latest ridge; (a), taken in 1993, shows the ridge from the west, where **Thinopyrum junceiforme* is dominant; (b), taken in 2000, shows it from the highest point near its eastern end, in the section dominated by *Austrofestuca littoralis*; (c) and (d), taken in 2003, show the eastern and western sections, (c) seen from **Thinopyrum junceiforme* mounds near the inlet shore, (d) from the spit plain; (e) is the view over the 2003 incipient ridge from the western end, showing groups of low mounds, mainly accumulated in **Thinopyrum junceiforme*.

Discussion

A comparison of the dunes on the spit with the dune ridges along Waratah Bay

The *Leptospermum laevigatum-Leucopogon parviflorus* scrub of the high dune ridge along Waratah Bay is typical of other calcareous dunes along the Victorian coast ((e. g. Parsons (1966), Hazard and Parsons (1977), Barson and Calder (1981), Conn (1993), Kirkpatrick (1993) and Ashton and van Gameren (2002)). Progradation of the shore has enabled the development of a sequence of new ridges along the foot of this high ridge. Each of these ridges went through a succession from grass-dominated vegetation to a closed scrub, in species composition similar to the scrub on the high dune. Although the spit is exposed to the same strong westerlies and south-westerlies, events there have followed a different pattern. Along the spit, in the absence of a foredune, flotsam only formed diffuse strand lines and during king tides washed up all over the spit. The scattered mounds established by the pioneer grasses bear witness to this process. The situation at the end of the high dune shows the transition from 'orderly' ridge formation along existing foredunes to scattered single mounds further out on the spit.

In the 20 years after their formation the vegetation on the ridges near the inlet at the base of the spit has hardly progressed beyond the pioneering stage. During the same period the vegetation succession on the ridges along the high dune had replaced the **Thinopyrum junceiforme* vegetation on ridge C with shrubbery of *Ozothamnus turbinatus* and *Olearia axillaris*. Only when the ridges along the inlet begin to link up with those at the southwest corner of the high dune, conditions may ameliorate sufficiently to provide the opportunity for further colonisation. This shows that ridges, open to wind from all directions, are too exposed to provide suitable conditions for further vegetation development.

Similar harsh conditions prevail at the windward side of the dune fields, where the vegetation has remained equally scanty and in addition to the grasses, only the most hardy of species, *Ozothamnus turbinatus* and *Actites megalocarpa*, grow there. However, the shore-parallel dune fields have provided a relatively sheltered environment along the inlet margin. Protected from the direct impact of fierce westerlies, new species have been able to establish. The process started with **Thinopyrum junceiforme* colonising the upper beach and higher-lying tidal flats. This provided a 'rough' surface in which sand and wind-dispersed propagules were caught. Over time, an open shrubland dominated by *Ozothamnus turbinatus*, *Olearia axillaris* and *Olearia glutinosa* was formed with *Isolepis nodosa* and various Asteraceous species common among the **Thinopyrum junceiforme* ground cover. Other species, not necessarily dispersed by wind, apppeared as well, for instance *Acacia sophorae*, *Leptospermum laevigatum* and *Leucopogon parviflorus* and herbs such as *Carpobrotus rossii*, **Melilotus indica* and *Acaena novae-zelandiae*. However, nowhere in this sheltered zone has the vegetation yet reached a stage that would indicate further succession to a closed woody vegetation as present on the older ridges along the Waratah Bay high dune. One reason may be that due to the isolated location this process has stalled because of an insufficient supply of woody plant propagules.

Propagule dispersal

For development of the spit beyond the bare sand plain stage, initial dispersal by water of propagules of the four pioneer grasses was crucial. Once plants thrived, wind contributed to further spread and the arrival of other species. Wind is also crucial for bringing in propagules of species that are only found on sheltered sites. At least half of the species presently occurring there are primarily dispersed by wind (Table 3). Species with small seeds, i.e. comparable in size to sand grains, also appear to fall into this category. Wind-dispersal is a random process; in principle any seed dispersed this way may germinate and grow if conditions are favourable. However, propagules will have to be carried either across the inlet or from the Waratah Bay high dune and hence, nearest seed sources are a kilometre or more away. This may explain why there are so few *Leptospermum laevigatum* present as it has a limited effective dispersal range (Hazard & Parsons 1977). *Banksia integrifolia* and *Allocasuarina verticillata* are still missing among the wind-dispersed woody species on the flats.

About 20 per cent of the species are animal-dispersed, local potential agents being birds and mammals. Red-necked Stints (*Calidris ruficollis*) and other small waders forage along the shoreline and on the tidal flats and hundreds of birds may shelter in the flotsam on the upper shore during high tide. They may be carriers of small seeds, e.g. those of *Isolepis nodosa*, but their role in dispersal is likely to be limited. This is also true for Cape Barren Geese (*Cereopsis novaehollandiae*) which rest occasionally on the spit and could have brought in propagules from the paddocks across the inlet. Once *Ozothamnus turbinatus* and other shrubs have established, White-fronted Chats (*Epthianura albifrons*) are quick to follow, but they forage for insects, as do most of the rare visitors, possibly migrants, such as Grey Fantail (*Rhipidura fuliginosa*) and Restless Flycatcher (*Myiagra inquieta*). The only seedeaters I have seen on the spit were a flock of European Goldfinches (**Carduelis carduelis*) actively feeding on ripe **Ammophila arenaria* heads in April 1994.

A more likely dispersal agent is the Red Fox (**Vulpes vulpes*) which regularly patrol the spit for carcasses and other food. For a while the latter must have included rabbits (**Oryctolagus cuniculus*), first noticed in 1990 and last seen in 1994. Rabbits like *Carpobrotus* fruits and could have brought in *Carpobrotus rossii* seeds. Although mostly carnivorous, foxes also eat berries and could have carried in seeds of *Leucopogon parviflorus* and *Exocarpos strictus* from the Waratah Bay dunes vegetation. In 2003 a Shortbeaked Echidna (*Tachyglossus aculeatus*) was present on the 1977–1979 flat and I have occasionally seen kangaroo prints on the inlet shore along the dune fields and once those of Hog Deer (**Axis porcinus*). Seeds could come in via the coat or dung of these animals.

In whatever way species have arrived at the sheltered side of the dune fields, seed dispersal could be still a limiting factor in advancing succession from the present open shrubland to a more closed woody vegetation. However, it could also be that the environment, although relatively benign compared with that prevailing elsewhere on the spit, is still too extreme to sustain succession.

*The new arrival: *Euphorbia paralias*

**Euphorbia paralias*, indigenous to the shores of southern Europe and northern Africa, was first found in Albany, Western Australia, in 1927 and has since spread to Geraldton in the west and southern New South Wales in the east. In several coastal dune areas it has established large populations and has been subjected to local attempts at eradication (Heyligers 2002).

When I started my investigations, **Euphorbia paralias* was not yet present in the Sandy Point area, but in the mid 1980s I found a few plants on the foredune along Waratah Bay and on the shore of Shallow Inlet across from the spit. It spread along the bay and over several stretches became co-dominant with **Thinopyrum junceiforme* on the youngest foredune. It was in October 1990 that I saw the first, already well-established plant on the spit, on the northwest corner of the 'Old Field.' During following visits I noticed the spread of **Euphorbia paralias* to other areas but, as shown on Tables 3 and 4, it rarely occurs in large numbers and is just another component of the heterogeneous flora of the more sheltered areas of the spit.

What would have happened without the foreign grasses?

The pioneering capacity of **Thinopyrum junceiforme* very much outweighs that of the native *Austrofestuca littoralis* and *Spinifex sericeus*. Most of the mounds on the spit have formed as a result of the presence of this species; the spit provides a niche similar to that of its habitat on the Waddenzee Barrier Islands along the south-eastern coast of the North Sea (Heyligers 1985). **Thinopyrum junceiforme* and **Ammophila arenaria* have been crucial for the formation of the dune fields along the shore of Shallow Inlet, again similar to the situation on the North Sea Islands. I surmise that these two species created opportunities for *Spinifex sericeus* and *Austrofestuca littoralis* to establish as well, and providing a seed source for further dispersal over the spit. *Austrofestuca littoralis* especially, can now be found in situations where at first only **Thinopyrum junceiforme* took hold, for instance along the inlet shore of the neck and at the far end of the spit. I seriously doubt that if *Austrofestuca littoralis* and *Spinifex sericeus* had formed incipient dune areas, these would have been sufficiently substantial to withstand the eroding forces of gales and overwash by king tides.

The development of *Thinopyrum* flats along the inlet shore appears to be solely due to the presence of **Thinopyrum junceiforme*. I do not know of any native species in the Shallow Inlet environs that could effectively replace it in this role. Admittedly, *Sarcocornia quinqueflora* and *Suaeda australis* occur among the **Thinopyrum junceiforme*, but never in such numbers to be effective as ridge builders. *Atriplex cinerea*, an important pioneer in ridge building along the outlet shore of Corner Inlet (Heyligers 1998), could be a candidate, but the only plant I have seen on the spit occurred on a ridge at the base. Hence, the *Thinopyrum* flats are a unique feature, intimately linked with the formation of the dune fields.

Conclusion

The sand spit of Shallow Inlet exists at the mercy of currents and winds. Longshore and tidal currents supply the sand, and westerly and southwesterly winds spread it over the spit. It accumulates in mobile ridges, incessantly resculptured by shifts in wind direction. Most likely this would still be the case were it not that, in the 1950s and 1960s, **Thinopyrum junceiforme* spread along the shores of Waratah Bay. This grass is native to the northwestern shores of Europe, where it is a primary coloniser of the upper beach. Being tolerant to salty groundwater, it thrived on the spit, under conditions too harsh for native dune grasses, and accumulated mounds where propagules took hold. These mounds, when close enough, developed into dune ridges and dune fields. This provided the opportunity for other hardy species to establish; foremost among these are *Austrofestuca littoralis*, **Ammophila arenaria* and *Spinifex sericeus*. However, the impressive dune landscape near the farther end of the spit exists in a state of uneasy balance between accretion and erosion, a condition that is too severe for any further vegetation development. Only on the somewhat sheltered slopes and flats along the inlet side of these dunes could more species establish, and although there is a successional trend in the composition of this vegetation, the area is relatively small and isolated; this appears to retard the arrival of species not adapted to dispersal by water or wind.

It is doubtful that any substantial dunes existed on the spit before it broke through in 1901 close to the high dune ridge as at that time neither **Thinopyrum junceiforme* nor **Ammophila arenaria* was present in the local area. Sooner or later another king tide is expected to break through the spit at its narrowest part, but I surmise that, at least initially, the dune fields will become an island. Over time, further erosion could undermine this island and lead to its demise. However, it is a sobering thought that two foreign grasses have had such a dominant influence on the formation of the landscape of the sand spit at Shallow Inlet.

Acknowledgements

First and foremost, I thank Jim Whelan and Paul McDiarmid, long-time rangers at Wilsons Promontory National Park, for their interest and support right from the start of my research on the dunes at the Park. Their co-operation as well as that of other Park staff is much appreciated. I also thank Mr D.S. Saunders, Director of National Parks, for issuing an 'enduring' research permit in 1986. I am most grateful to Phillip Rogers and Pauline and Michael Tarrant for letting me stay at their 'retreats' at Sandy Point. It has greatly simplified the logistics for fieldwork, not to mention that in the inimical weather of the Bass Strait coast it was very nice to have a cozy refuge. I am also indebted to Prof J. van Andel, University of Groningen, The Netherlands, for hospitality at the University's field station on Schiermonnnikoog, one of the Waddenzee Barrier-Islands.

During my gathering of historical information I have received much appreciated help from many people. Hence, I am still indebted to Dr Sandra Bardwell, historian, National Parks Service, Mr Jack Cavanah, Divisional Photographer, CSIRO Water and Land Resources, Mr W.D. Crawford, South Gippsland Shire Historical Society, Mr J. Ros. Garnet, author, Messrs D.R. Paterson and S. Zallar, Soil Conservation Authority, Ms Violet Pilkington, 'Gyndahnook,' Sandy Point, Ms Ann Smith, and to members of staff at the Surveyor General's Office, the State Library of Victoria (map section), the LaTrobe Library and, in Canberra, at CSIRO Archives and Black Mountain Library.

I thank the Chief, CSIRO Sustainable Ecosystems for my Honorary Fellowship, Raymond Smith and Pina Milne, National Herbarium of Victoria, and Laurie Adams and Brendan Lepschi, Australian National Herbarium, for specimen identification, Bob Parsons, LaTrobe University, for references, Hans van Elmpt, Parks Victoria, Michael Tarrant and Wilfred Tuddenham for aerial photography, and Violet Pilkington, Ann Smith and Jim Whelan for historical pictures. A special thanks goes to Peter Fullagar for scanning and processing the many pictures used for the paper. Sections of the vertical aerial photographs have been reproduced with the kind permission of Geoscience Australia, the Royal Australian Air Force, the Department of Sustainability and Environment, Parks Victoria and the Surveyor General, Victoria, which retain the respective copyrights of the photographs. I am much indebted to David Ashton, Doug Benson, Bob Parsons, Jill Whiter and an anonymous person for reviewing the draft. The paper has benefited a great deal from their comments.

I dedicate this paper to the memories of Violet Pilkington and Phillip Rogers, staunch advocates for the conservation of Shallow Inlet and its environs.

References

Anon. 1986 *The South Gippsland Marine and Coastal Parks*. Pamphlet, Department of Conservation Forests and Lands – Victoria.

Anon. 1990 *Shallow Inlet Marine and Coastal Park Proposed Management Plan*. Department of Conservation Forests and Lands – Victoria. 59 pages.

Ashton, D.H. & van Gameren, M. (2002) Vegetation of sand dunes at Wilsons Promontory, Victoria. *Proceedings of the Royal Society of Victoria* 114: 43–58.

Barson, M.M. & Calder, D.M. (1976) *Sites of Special Scientific Interest in the Victorian Coastal Region*. Report on botanical aspects prepared for Town and Country Planning Board, Melbourne.

Barson, M.M. & Calder, D.M. (1981) The vegetation of the Victorian coast. *Proceedings of the Royal Society of Victoria* 92: 55–65.

Belcher, R.O. (1994) The *Senecio* aff. *lautus* complex (Asteraceae) in Australia. II Clarification of names given to pseudolautusoid Australian specimens of *Senecio* by Richard and by Candolle. *Australian Systematic Botany* 7: 1–85.

Bird, E.C.F. (1977) *Sites of Special Scientific Interest in the Victorian Coastal Region*. A report on geological and geomorphological aspects prepared for the Town and Country Planning Board, Melbourne.

Bird, E.C.F. (1993) *The coast of Victoria; the shaping of scenery*. (Melbourne University Press: Melbourne).

Bourman, R.P. (1986) Aeolian sand transport along beaches. *Australian Geographer* 17: 30–34.

Cecil, M.K. (1983) *The evolution of the entrance to Shallow Inlet, Waratah Bay, South Gippsland*. Unpublished Report 1983/71, Geological Survey of Victoria, 24 pages.

Christides, L. & Boles, W.E. (1994) *The taxonomy and species of birds of Australia and its Territories*. RAOU Monograph 2. (Royal Australasian Ornithologists Union: Melbourne).

Conn, B.J. (1993) Natural regions and vegetation of Victoria. Pp. 79–158 in: D.B. Foreman & N.G. Walsh (eds.) *Flora of Victoria*, Vol. 1 Introduction. (Inkata Press: Melbourne).

Cooper, W.S. (1958) Coastal sand dunes of Oregon and Washington. *Geological Society of America, Memoir* 72.

Crawford, R. (1984) *Yanakie, station to settlement 1850–1983*. Yanakie Hall Committee. (ISBN 0 9591185 0 0)

Danin, A. (1996) *Plants of desert dunes*. (Springer-Verlag: Berlin Heidelberg).

Danin, A., Rae, S., Barbour, M., Jurjavcic, N., Connors, P. & Uhlinger, E. (1998) Early primary succession on dunes at Bodega Head, California. *Madroño* 45, 101–109.

Garnet, J. Ros. (1971) *The wildflowers of Wilson's Promontory National Park*. (Lothian Publishing Company: Melbourne).

Hazard, J. & Parsons, R.F. (1977) Size-class analysis of coastal scrub and woodland, Western Port, southern Australia. *Australian Journal of Ecology* 2: 187–197.

Hesp, P.A. (1981) The formation of shadow dunes. *Journal of Sedimentary Petrology* 51: 101–112.

Hesp, P.A. (1982) *Dynamics and morphology of foredunes in southeast Australia*. Ph D dissertation, University of Sydney.

Hesp, P. & McLachlan, A. (2000) Morphology, dynamics, ecology and fauna of *Arctotheca populifolia* and *Gazania rigens* nabkha dunes. *Journal of arid environments* 44: 155–172.

Heyligers, P.C. (1985) The impact of introduced plants on foredune formation in southeastern Australia. *Proceedings of the Ecological Society of Australia* 14: 23–41.

Heyligers, P.C. (1988) *Dune and vegetation formation at the Entrance Point Scientific Reference Area, Wilsons Promontory National Park, Victoria.* M I Partners Report No. 8 (M I Partners, PO Box 236: Moruya NSW 2537).

Heyligers, P.C. (2002). The spread of the introduced *Euphorbia paralias* (Euphorbiaceae) along the mainland coast of southeastern Australia. *Cunninghamia* 7(3): 101–106.

Kirkpatrick, J.B. (1993) Dry coastal ecosystems of southeastern Australia. In: E. van der Maarel (ed.) *Dry Coastal Ecosystems; Africa, America, Asia and Oceania.* Ecosystems of the World Vol. 2B: 273–288.

Love, R. (1999) Reefscape. *Meanjin* 3: 215–220.

Molineux, A. (1902) Marram grass at Port Fairy, Victoria. *Journal of Agriculture and Industry* 5: 604–607.

Moore, C.J. & Scott, G.A.M. (1979) The ecology of mosses on a sand dune in Victoria, Australia. *Journal of Bryology* 10: 291–311.

Parsons, R.F. (1966) The soils and vegetation at Tidal River, Wilson's Promontory. *Proceedings of the Royal Society of Victoria (n.s.)* 79: 319–354.

Rundle, P.W., Dillon, M.O., Palma, B., Mooney, H.A., Gulmon, S.L. & Ehrleringer, J.R. (1991) The phytogeography and ecology of the coastal Atacama and Peruvian deserts. *Aliso* 13: 1–49.

Smith, A.S. (1969) *The Geomorphology of Shallow Inlet, Victoria.* BSc (Hons) thesis, University of Melbourne. 76 pages.

Soil Conservation Authority, Victoria (1960) Sand stabilization, species trials. Annual Report No. 11: 21.

Triggs, B. (1996) *Tracks, scats and other traces.* (Oxford University Press: Melbourne).

Walsh, N.G. & Entwisle, T.J. (eds.) (1994–1999) *Flora of Victoria,* vols. 2–4. (Inkata Press: Melbourne).

Manuscript accepted 9 August 2006

Information for authors

***Cunninghamia*: a journal of plant ecology for eastern Australia** publishes original research papers on all aspects of plant ecology with particular emphasis on the vegetation and flora of eastern Australia. Descriptive, experimental and historical studies of plant communities, populations, individuals, their interactions with other organisms and their management are acceptable. Acceptance is the responsibility of an editorial committee chaired by the Scientific Editor. All papers are peer-reviewed.

Cunninghamia is published twice a year by the Royal Botanic Gardens and Domain Trust.Two copies of the manuscript should be submitted along with originals of photographs and figures. Please supply full contact details for main author.

Formatting

- The title should be explicit and descriptive of the content; a short running head and an abstract should be included.
- Check most recent issue for format. The Macquarie Dictionary, latest edition, and the Style Manual for Authors, Editors and Printers, latest edition, should be consulted for spelling, abbreviations, units and other conventions. Genera should be spelt out in full throughout the text.
- References in the text should be made by giving the author's name with the year of publication in parentheses. For reference list at end of paper see papers in the latest issue for style. Titles of journals should be given in full.

Supply of Artwork

- Captions and scale bars for figures should be checked against the artwork supplied for consistency. If scale bars or lettering need to be added, they should be clearly marked on a photocopy of the artwork.
- Line Art @ 1200 dpi, resolution in eps or tiff format please. Authors wishing to submit other types of files will need to contact the Editor.
- Greyscale Art @ 300 dpi resolution in eps or tiff format please. Authors wishing to submit other types of files will need to contact the Editor.
- Files from ArcView 3.2 are acceptable if exported from the layout as Postscript New (eps) at a minimum resolution of 720 dpi. This must be specified in the options box.
- At the above resolutions, graphic file size will usually exceed 1.2 Mb and therefore will not transport via email or on a floppy disk. Please supply graphics either on a 100 Mb zip disk or burnt to CD or DVD Macintosh compatible please.
- Graphics embedded in Microsoft Word, Excel and Power Point will not be accepted. Items should be saved in the graphic formats tiff and eps as for Line art and Greyscale art.

Artwork supplied as hard copy only

- Artwork supplied should be no larger than A4 (21 cm wide). Any larger images should be brought to the attention of Scientific Editor to see if they need to be outsourced or reduced
- Hard copy Artwork should be complete and legible as no changes to hard copy artwork can be made post scanning. Any images requiring special treatment (e.g. old maps) should be brought to the attention of the Scientific Editor prior to acceptance of the paper

Tables

- Tables should preferably be portrait rather than landscape shape i.e. taller rather than wider. Column headings should be brief. Each table must be referred to in the text and its approximate position should be indicated. Please remember that tables need to fit into the journal page size.

Fold-up Maps

- Authors wishing to submit large or complex maps should discuss proposals with the Scientific Editor.

Cunninghamia

A journal of plant ecology for eastern Australia

Volume 9(4): 451–595 • 2006

This disastrous event staggered me: Reconstructing the botany of Ludwig Leichhardt on the expedition from Moreton Bay to Port Essington, 1844-45
R. J. Fensham, A.R. Bean, J. L. Dowe and C. R. Dunlop 451

Leaf, tree and soil properties in a *Eucalyptus saligna* forest exhibiting canopy decline
Christine Stone and Jack A. Simpson 507

Quantifying the abundance of four large epiphytic fern species in remnant complex notophyll vine forest on the Atherton Tableland, north Queensland, Australia
Jason Cummings, Michelle Martin and Anne Rogers 521

The effect of population structure, plant size, herbivory and reproductive potential on effective population size in the temperate epiphytic orchid, *Sarcochilus australis*
Raymond Tremblay 529

The natural distribution and ecology of *Blandfordia cunninghamii* (Blandfordiaceae)
David Coleby 537

African Olive (*Olea europaea* subsp. *cuspidata*) as an environmental weed in eastern Australia: a review
Peter Cuneo and Michelle R. Leishman 545

Distribution and diversity of exotic plant species in montane to alpine areas of Kosciuszko National Park
Roxana Bear, Wendy Hill, Catherine M.Pickering 559

Primary vegetation development on the sand spit of Shallow Inlet, Wilsons Promontory, southern Victoria
Petrus C. Heyligers 571